Volume 14 JULY 1930 Number 7

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS

SYFO CLINOGRAPH

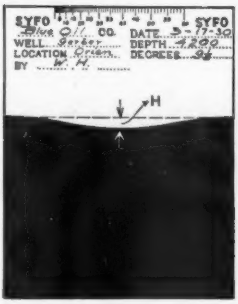
A device for the daily recording of vertical deviation in drilling. Permanent Records » » Quickly Made » » No Danger » » Inexpensive » » Direct and Accurate.

RECOGNITION that careful drilling can obviate much of the deviation from the vertical in drilling, has caused several devices to come on the market to guard the driller against getting off the vertical. Most common of these devices is the Acid Bottle — dangerous to handle, slow and rather unsatisfactory in result. Other devices have followed, but not until the Sperry-Sun Well Surveying Company perfected the SYFO Clinograph can the problem be said to have been solved in a way to satisfy the driller and producer.

The operation of the SYFO is simple, the results obtained of great accuracy and can be read directly without computations. Being on paper, these records can be filed for reference. A SYFO test is quick and the serivce most reasonable in cost.

The SYFO Clinograph represents a radical improvement in the design and method of operation of inclination measuring instruments. Its advantages may be summarized as follows: It affords a *direct and accurate record*. The record is *easily obtained* without the use of *dangerous acids*. The test is *quickly* made. The record is on *paper* and can be *filed* for reference. *Ruggedly* built and will operate without decrease in efficiency. Operates on wire line running through the drill stem, or on sand or bailing line in open hole, or can be dropped into the hole by the "Go-Devil" method prior to pulling out the drill stem.

Many operators are writing into their drilling contracts fixed limits from the vertical before accepting the completed well from the contractor. Record sheets from SYFO Clinograph tests should be used as evidence.



The SYFO Clinograph is not sold, but leased at nominal rates. Being made in different sizes for different depths, it is necessary for the drilling company to advise the conditions under which the surveying will be done before quotation can be made.

SPERRY-SUN WELL SURVEYING CO.

Main Office—1608 Walnut Street

DALLAS PHILADELPHIA TULSA

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

The Bulletin of The American Association of Petroleum Geologists is published by the Association on or about the 15th of each month. Editorial and publication office, 504 Tulsa Building, Tulsa, Oklahoma, Post Office Box 1852. Cable address, AAPGEOL.

The subscription price to non-members of the Association is \$15.00 per year (separate numbers \$1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of \$0.40 is made on each subscription to cover extra wrapping and handling.

British agent: Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4.

German agent: Max Weg, Königstrasse 3, Leipzig, Germany.

Claims for non-receipt of preceding numbers of the BULLETIN must be sent to the business manager within three months of the date of publication in order to be filled gratis.

Back numbers of the BULLETIN can be ordered from the business manager at the following prices: Vol. 2, \$4.00; Vol. 3, \$5.00; Vol. 4, numbers 2 and 3, each \$3.00; Vols. 5 and 6, cloth bound, each \$12.00; Vols. 7 and 8, cloth bound, each \$11.50; separate numbers, each \$2.00 except Vol. 5, No. 2, \$3.50; Vols. 9, 10, 11, 12, 13, cloth bound, each \$17.00; separate numbers each \$1.50, except Vol. 9, numbers 1, 2, and 3, each \$3.00, Vol. 10, numbers 3, 11, and 12, each \$2.00, and Vol. 11, number 3, \$2.00. Symposium, Theory of Continental Drift, 240 pp., 29 illus., \$3.50. 10-Volume Index (1917-1926), \$2.00. Structure of Typical American Oil Fields, Vol. I, 510 pp., 194 illus., \$5.00 (\$4.00 to members); Vol. II, 780 pp., 235 illus., \$6.00 (\$4.00 to members).

The BULLETIN furnishes thirty-five free reprints of major papers. Additional reprints and covers for all or part, are furnished at cost. **Orders for reprints** should accompany corrected galley proof.

Association Headquarters—504 Tulsa Building, East Fifth Street at Cincinnati Avenue, Tulsa, Oklahoma.

Communications about the Bulletin, manuscripts, editorial matters, subscriptians, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to

J. P. D. HULL, *Business Manager*

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

BOX 1852

TULSA, OKLAHOMA

Entered as second-class matter at the Post Office of Tulsa, Okla., under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

MID-WEST PRINTING CO., TULSA, OKLA., U. S. A.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

OFFICERS FOR THE YEAR ENDING MARCH, 1931

SIDNEY POWERS, *President*
Tulsa, Oklahoma

J. Y. SNYDER, *Past-President*
Shreveport, Louisiana

R. D. REED, *First Vice-President*
Los Angeles, California

MARVIN LEE, *Second Vice-President in Charge of Finances*
Wichita, Kansas

FREDERIC H. LAHEE, *Third Vice-President in Charge of Editorial Work*
Dallas, Texas

DISTRICT REPRESENTATIVES

(Representatives' terms expire immediately after annual meetings of the years shown in parentheses.)

Abilene:
M. G. Cheney (1931), Coleman, Tex.
Amarillo:
Victor Cotner (1932), Amarillo, Tex.
Appalachian:
R. E. Somers (1931), Pittsburgh, Pa.
Ardmore—Oklahoma City:
Hubert E. Bale (1931), Oklahoma City, Okla.
Canada:
Theodore A. Link (1931), Calgary, Can.
Capital:
H. D. Miser (1930), Washington, D. C.
Dallas:
Willis Storm (1930), Dallas, Tex.
Enid:
Glenn C. Clark (1930), Ponca City, Okla.
Fort Worth:
H. B. Fuqua (1931), Fort Worth, Tex.
Great Lakes:
A. C. Trowbridge (1931), Iowa City, Iowa
Houston:
J. M. Vetter (1931), Houston, Tex.
Mexico:
S. A. Grogan (1931), Tampico, Mex.
New York:
H. J. Wasson (1931), New York, N. Y.
Pacific Coast:
C. R. McCollom (1930), Los Angeles, Calif.
E. F. Davis (1931), Los Angeles, Calif.
Frank A. Morgan, Jr., (1931), Los Angeles, Calif.
Rocky Mountains:
H. A. Stewart (1930), Denver, Colo.
Charles M. Rath (1931), Denver, Colo.
San Angelo:
R. F. Imbt (1931), San Angelo, Tex.
San Antonio:
Chas. H. Row (1931), San Antonio, Tex.
Shreveport:
S. P. Borden (1931), Shreveport, La.
South America:
R. E. Dickerson (1931), Maracaibo, Venezuela, S. A.
Tulsa:
A. W. Duston (1931), Tulsa, Okla.
A. I. Levorsen (1931), Tulsa, Okla.
Wichita:
L. W. Kesler (1931), Wichita, Kan.
Wichita Falls:
C. W. Clark (1930), Wichita Falls, Tex.
Representatives-at-large:
Donald C. Barton (1931), Houston, Tex.
Alexander Deussen (1931), Houston, Tex.
Alex W. McCoy (1931), Ponca City, Okla.

PACIFIC SECTION

(Chartered, March, 1925)

RALPH D. REED, *President*, 1110 Glendon Way, South Pasadena, California
H. K. ARMSTRONG, *Secretary-Treasurer*, 453 Roosevelt Building, Los Angeles, California

Membership is restricted to members of the A.A.P.G. in good standing, residing in the Pacific Coast states. Dues of $2.00 per year are payable to the secretary-treasurer of the Pacific Coast Section. Members of the A.A.P.G. transferring to the Pacific Coast are cordially invited to become affiliated with the local section, and to communicate their change of address promptly to the secretary-treasurer of the Pacific Section.

SAN ANTONIO SECTION

(Chartered, April, 1929)

D. R. SEMMES, *President*, 1601 Milam Building, San Antonio, Texas
ED. W. OWEN, *Secretary-Treasurer*, 1015 Milam Building, San Antonio, Texas

Membership is limited to persons who are eligible to membership in The American Association of Petroleum Geologists. Annual dues: $2.50. Annual meeting: the last Friday in February.

MARACAIBO SECTION

(Chartered, April, 1930)

J. B. BURNETT, *President*, Lago Petroleum Corporation, Maracaibo, Venezuela
P. E. NOLAN, *Secretary*, Venezuela Gulf Oil Company, Maracaibo, Venezuela

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Affiliated, March, 1928; chartered, technical division, April, 1930)

JOSEPH A. CUSHMAN, *President*, Sharon, Massachusetts
GAYLE SCOTT, *Secretary-Treasurer*, Texas Christian University, Fort Worth, Texas

The Society issues a quarterly, the *Journal of Paleontology*, RAYMOND C. MOORE, *Editor*, University of Kansas, Lawrence, Kansas. Membership application forms and back numbers of the *Journal* may be obtained from A. A. P. G. Headquarters, Box 1852, Tulsa, Oklahoma.

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Volume 14 **JULY 1930** **Number 7**

CONTENTS

Articles Scheduled for Publication in the August *Bulletin*

Transverse Cross Section of Permian Basin, West Texas and Southeast New Mexico

By LON D. CARTWRIGHT, JR.

Deep Sand Development in Cotton Valley Field, Webster Parish, Louisiana

By J. S. ROSS

Geothermal Variations in Oil Fields of Los Angeles Basin, California

By ANDERS J. CARLSON

Geology of Vermilion Creek Gas Area in Southwest Wyoming and Northwest Colorado

By W. T. NIGHTINGALE

Contribution to Salt-Dome Problem

By F. M. VAN TUYL

Use of Airplane Photographs in Geologic Mapping

By WALTER A. ENGLISH

Example of Deflecting Diamond-Drill Holes

By ROBERT DAVIS LONGYEAR

Volume 14 Number 7

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JULY 1930

FAULTING IN SOUTHWESTERN ARKANSAS[1]

C. L. RANKIN[2]
Lake Charles, Louisiana

ABSTRACT

A system of faults in southwestern Arkansas extends from the faulted Irma field in southern Nevada County, Arkansas, southwestward across Lafayette and Miller counties, nearly to the Texas state line. The grabens range in width from 2 to 3 miles and have a total length of 50 miles. This series of faults follows the strike of the Wilcox-Claiborne contact along the northern part of the alignment, but along the southwestern part the line of weakness advances down-dip until this faulted zone lies entirely within the area of the Claiborne outcrop.

The Falcon fault, outlined at the surface by the division of non-marine beds of the Wilcox and Claiborne formations into lithologic units on the basis of their typical ferruginous concretions, was later verified by geological test wells. From the Lewisville fault in Lafayette County, westward, the faulted zone is obscured by a mantle of alluvium and Quaternary sand and gravel and was outlined by shallow geological test wells.

Thirty-seven geological test wells were drilled along the faulted zone, disclosing three closures against the southern boundary of the grabens. One deep test on the Falcon closure tested all of the sands of the Upper Cretaceous and 1,300 feet of the Lower Cretaceous. This well, which was favorably located with reference to the geological structure, yielded only showings of oil and gas. As the result of this work it is felt that although seemingly the most promising areas along this fault zone have been carefully tested, there still remains some possibility of opening deep commercial pools between the Irma field and the Texas state line.

INTRODUCTION

In the spring of 1924, at the suggestion of Wallace E. Pratt, the Humble Oil and Refining Company began an investigation of the possibilities of the extension of the Mexia fault zone or some allied system

[1]Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, February 28, 1930. Published by permission of the Humble Oil and Refining Company.

[2]Humble Oil and Refining Company.

of faults eastward from Texas into southwestern Arkansas. At that time the northward and northeastward extensions of the Mexia fault zone through Kaufman, Hunt, Hopkins, Franklin, and Titus counties, Texas, were being investigated in great detail and the prospect seemed excellent for the discovery of fields similar to Mexia or Powell along these more northerly faults.

It was known that at least three fields in south Arkansas were located along large faults, namely, Smackover, Irma, and Stephens; therefore, the area between these faults and those in northeast Texas that had been traced almost to the Arkansas line seemed most desirable to examine for surface evidence.

The writer spent part of the summer of 1924 in surface work west and southwest of the Irma fault and succeeded in finding stratigraphic and other evidence of the continuation of the faulting from the Irma field southwestward across parts of Nevada and Lafayette counties. Some months later, R. L. Cannon, a geologist who had done considerable work for the Humble Oil and Refining Company in the fault zone of northeast Texas, was convinced by subsurface evidence that a fault existed in western Lafayette County, Arkansas, near Lewisville, and surmised that this fault continued westward through Miller County. He then interested the Humble Oil and Refining Company in acquiring leases in a part of Lafayette County and in Miller County.

DRAINAGE AND TOPOGRAPHY

Red River, with its 8-mile-wide bottoms, flows through the central part of the area, with Sulphur River, a tributary, flowing southeastward across the extreme southwestern part of the faulted area. Many tributaries flow into these streams, the largest being east of Red River. Immediately west of the town of Stamps, Bodcaw Bayou flows southward across the fault. Dorcheat Bayou flows southward across the eastern end of the faulted area.

The altitudes in Miller County range from about 220 feet to 350 feet. East of Red River, the greatest relief is found near the town of Falcon, in Nevada County, where some of the hills have an elevation of more than 400 feet above sea-level. The lowlands between Stamps and Falcon average 250 feet above sea-level.

The topography of the northeastern part of the faulted area is characteristic of the general area of the Claiborne and Wilcox outcrops in south Arkansas. Hard ferruginous layers in the Wilcox have caused certain areas to resist weathering better than others, forming a somewhat

TABLE I

GEOLOGICAL TEST WELLS OF THE HUMBLE OIL AND REFINING COMPANY
NEVADA, LAFAYETTE, AND MILLER COUNTIES, ARKANSAS

Reference Number on Figure 1	*Farm and Well Number*	*Section, Township, Range*		*Elevation (Feet)*	*Total Depth (Feet)*	*Top of Nacatoch (Feet)*	*Remarks*
1	Bodcaw-Fee 2	SW. SE.	9–15–22	305.24	1,247	1,212	Normal
2	Bodcaw-Fee 4-A	NE. SE.	9–15–22	285.35	3,888	1,193	Normal. 1,300 feet into Trinity
3	Bodcaw-Fincher 1	SE. NW.	6–15–22	312.0	1,214	1,171	Normal
4	T. W. Calloway 1	NE. NW.	10–15–22	269.5	1,319		Graben. Stopped in Midway
5	T. W. Calloway 2	SE. NE.	10–15–22	268.3	1,231	1,225	Normal
6	J. D. Pelt 1	NW. SE.	8–15–22	337.45	1,673	1,666	Graben. Approximate throw, 400 feet
7	Traylor 1	NE. NW.	11–15–22	275.94	1,327	1,286	Normal
8	Bodcaw-Fee 1	SW. SW.	17–16–23	253.0	1,460		Graben. Stopped about middle of Midway
9	Bodcaw-Fee 3	NE. NE.	19–16–23	246.0	1,352	1,291	Normal
10	Bodcaw-Kitchens 1	SE. NE.	24–15–23	278.59	1,317		Graben. Stopped near top of Midway
11	Bodcaw-Reed 1	C. NW.	16–15–22	289.45	2,501	1,208	This well cut fault plane about 250 feet above Nacatoch
12	Bodcaw-Riggins 1	SE. NW.	21–15–22	278.43	1,419	1,373	Normal
13	Bodcaw-Riggins 2	NW. NW.	30–15–22	275.75	1,408	1,403	Normal
14	Bodcaw-Warren 1	NW. NW.	15–15–22	279.07	1,300	1,247	Normal
15	R. L. Bradshaw 1	SE. NE.	27–16–25	220.0	1,422		Graben. Stopped in Arkadelphia
16	E. A. Ford 1	NE. NE.	28–16–24	274.83	1,513	1,507	Normal
17	A. S. Johnson 1	NW. SE.	23–16–25	220.50	1,114		Graben. Stopped in upper Midway
18	L. W. Knighton 1	NE. SE.	3–16–23	343.0	1,480		Graben. Stopped in middle Midway
19	Massie 1	SE. SW.	24–16–24	269.03	1,389	1,341	Normal
20	McClemdon 1	SE. SW.	15–16–24	262.0	859		Graben. Stopped in Wilcox
21	Shurtleff 1	NW. SW.	3–16–23	304.80	1,465		Graben. Stopped in upper Midway
22	Big Pine Lbr. Co. 1	NE. SW.	33–17–27	250.4	1,714		Graben. Stopped in calcareous basal Midway
23	G. W. Bishop 1	NE. NE.	19–16–27	371.0	1,321	1,315	Normal
24	John Crank 1	NW. NW.	5–17–25	220.0	1,572	1,555	Normal
25	Dickerman Inv. Co. 1	SW. SW.	11–17–28	230.93	1,403	1,393	Normal
26	Eagle Chute 1	SW. SW.	23–17–28	208.0	1,494	1,483	Normal
27	B. H. Fouke 1	NE. NE.	35–16–27	257.17	1,760	1,757	Graben. Approximate throw, 300 feet
28	C. W. Fouke Estate 1	SW. SW.	2–17–27	315.86	1,735		Graben. Stopped in calcareous basal Midway
29	Goodson 1	SW. NW.	30–16–27	314.74	1,317	1,293	Normal
30	Mann Ld. & Imp. Co. 1	NW. SE.	15–16–26	220.0	1,343	1,333	Normal
31	Mann Ld. & Imp. Co. 2	SE. SE.	22–16–26	220.0	1,045		Graben. Stopped in Wilcox
32	Mann Ld. & Imp. Co. 3	NW. NW.	35–16–26	220.0	1,486		Graben. Stopped in Midway
33	M. H. McKnight 1	NW. NW.	17–17–26	304.0	1,560		Normal. Stopped in calcareous basal Midway
34	Miller Ld. & Lbr. Co. 1	NW. SE.	3–18–28	216.0	1,613	1,592	Normal
35	Red River Farms 1	NW. NW.	2–17–26	220.0	1,598		Graben. Stopped in calcareous basal Midway. Throw, 300 feet
36	Red River Farms 2	SW. SW.	2–17–26	220.0	1,574	1,541	Normal
37	J. W. Vann 1	NE. SW.	36–16–28	266.64	1,318	1,303	Normal

rugged terrain. A sharp break in topography, striking northeast, is found along the northern boundary of the graben near the town of Falcon, where a thick sand section of upper Wilcox in normal position forms a high, rounded, sand-hill topography in contrast to the more gently rolling terrain of lignitic clay of the graben area.

Westward from Stamps, nearly to the Texas state line, either alluvium or a mantle of Quaternary sand and gravel obscures the surface evidence of the faulted zone.

ACKNOWLEDGMENTS

The writer is indebted to L. T. Barrow, W. C. Spooner, and L. P. Teas for helpful discussion and criticism in the preparation of this paper.

HISTORY OF DEVELOPMENT

The drilling of shallow tests to determine the actual position and extent of the faults was begun in the fall of 1924 and continued until the summer of 1927, throughout an area extending from southwestern Nevada County to western Miller County, Arkansas. As shown in Table I, thirty-seven shallow tests were drilled by the Humble Oil and Refining Company in the area under discussion. During this time one well was drilled to a depth of 2,500 feet and another to 3,888 feet to test deeper sands in the structure south of the town of Falcon. More recently, three additional wells have been drilled along the fault by independent operators. Although several faults and three closed structures were revealed by this work and several excellent showings encountered, oil in commercial quantities was not found. In the course of this development, sands ranging from Nacatoch to horizons about 1,300 feet deep in the Trinity were cored and tested on the Falcon structure. As a result of this work it is felt that, although seemingly the most promising areas along this fault zone have been carefully tested, there still remains some possibility of opening deep commercial pools between the Irma field and the Texas state line.

STRATIGRAPHY

EXPOSED TERTIARY

Claiborne formation.—The stratigraphic section of the Falcon and adjacent areas is shown in Table II.

The beds at the surface, belonging to the Claiborne and Wilcox formations, are obscured by alluvium and a thick mantle of Quaternary sand and gravel.

TABLE II

STRATIGRAPHIC SECTION OF THE FALCON AND ADJACENT AREAS

System	*Series*	*Formation*	*Thickness in Feet*	*Character*
		Claiborne (undifferentiated)	0–400	Gray and pale red sandy clay and argillaceous sands. A few thin horizons of ferruginous sandy clay with some glauconite in the middle and basal parts
TERTIARY	Eocene	Wilcox	600–700	Brown and gray, lignitic, sandy clays and sands
		Midway	500	Dark gray, fine-textured, slightly sandy clay with some bentonite in the upper part. Gray, calcareous, fossiliferous clay in the lower 50 feet
		Unconformity		
		Arkadelphia marl	100–125	Gray, calcareous, fossiliferous clay
		Nacatoch sand	300	Sand and gray shale with some limestone
		Saratoga chalk	50	Shale and gray chalk. The Saratoga chalk in this area* is very difficult, if not impossible, to differentiate from the Marlbrook and is here represented as a thin, somewhat indurated zone overlying typical Marlbrook
		Marlbrook marl	200	Gray, calcareous shale and marl
		Annona chalk	50	Gray chalk and marl
UPPER CRETACEOUS	Gulf	Ozan	150	Somewhat sandy gray shale. The Buckrange sand horizon is very poorly expressed at the base of the formation as very argillaceous sand and sandy shale
		Brownstown marl	150–200	Gray, fossiliferous clay, with sandy clay and thin sand horizons
		Tokio	350	Gray, sandy, fossiliferous shale with some volcanic ash in sand horizons in the lower part
		"Woodbine" sand		Gray and pale green-gray sand and clay containing volcanic ash, with some non-fossiliferous sandstone
		Unconformity		
CRETACEOUS	Comanche	Glen Rose	800	Gray sandstone, gray, green, and red shale, with some fossiliferous Glen Rose limestone. A thin horizon of celestite occurs near the top of the section, with limestone and shale in the basal part
		Red shale and sand zone	500+	Red, gray, and green shale and sandstone

*T. E. Morrison.

The notably glauconitic Lower Claiborne of East Texas is poorly expressed in the immediate vicinity of the fault as a sandy clay with a few thin horizons of glauconitic, sandy clay, principally in the graben area. There was probably a barrier in the faulted area extending from southwestern Nevada County, westward across Lafayette and Miller counties nearly to the Texas state line, separating the shallow Claiborne sea of East Texas and a deeper Claiborne basin of southern Arkansas.

Wilcox formation.—The Wilcox at the surface is made up of a series of non-marine, gray, argillaceous sands, brown and black lignitic clays with horizons of ferruginous concretions, and some ferruginous sandstone, which, locally, is quartzitic. The exposed Wilcox has a thickness of about 300 feet.

UNEXPOSED TERTIARY

Wilcox formation.—The lower Wilcox, not exposed in the faulted area, consists of a monotonous series of gray, brown, and black, lignitic sandy clays and argillaceous sands, altogether about 400 feet thick. Siderite concretions of local extent occur at several horizons throughout the Wilcox formation. The basal bed of the Wilcox found in some of the shallow test wells consists of fine-textured, somewhat glauconitic sand 50 feet thick, which in a short distance changes laterally to dark gray, somewhat lignitic, sandy clay.

Midway formation.—Inasmuch as the basal Wilcox and the highest Midway are lithologically similar, it is very difficult to differentiate one distinctly from the other. The highest Midway, though it is sandy and contains considerable mica, is somewhat finer-textured than the overlying Wilcox and does not have the brownish tint which is characteristic of the Wilcox formation. This type of lithology does not ordinarily extend downward in the Midway section more than 50 feet, at which depth is found the dark gray, fine-textured, brittle clay typical of the upper Midway. Cuttings and cores from this part of the section are a very deep gray to black when first brought to the surface, but, upon drying, change to dark gray. In the upper part of this section are thin beds of bentonite. The basal 50 feet of the Midway formation consists of gray, calcareous, highly fossiliferous clay. A few arenaceous *Foraminifera* are present high in the section, but calcareous *Foraminifera* are not commonly present in the upper 300 feet of the formation.

GULF SERIES (UPPER CRETACEOUS)

Arkadelphia marl.—This marl section is made up of 100-125 feet of gray, very calcareous, fossiliferous clay, which most drillers record as chalk.

Nacatoch sand.—The Nacatoch sand has a thickness of 300 feet and is made up of a series of sands with interbedded thin horizons of limestones, sandstones, and clays in the upper part. The lower part of the Nacatoch consists principally of gray clays with subordinate beds of argillaceous limestone. The highest beds of the Nacatoch exhibit considerable lateral variation shown in some places by the following sequences: cap rock of calcareous sandstone, underlain by a stratum of sand, ranging from a few feet to 50 feet in thickness; cap rock underlain by a thin section of Nacatoch clay above the sand. In other places no cap rock is present and the Arkadelphia clay is in contact with Nacatoch sand.

Saratoga chalk.—The Saratoga chalk consists of a gray chalk not more than 50 feet thick, and in this area, according to Morrison,[1] is very difficult, if not impossible, to differentiate from the Marlbrook marl. It is here represented as a thin, somewhat indurated zone overlying typical Marlbrook marl.

Marlbrook marl.—Below the Saratoga chalk the Marlbrook marl, consisting of gray, calcareous shale and marl, occupies a section of about 200 feet.

Annona chalk.—This gray chalk and marl section, 50 feet thick, underlies the Marlbrook marl. The Wolfe City sand[2] is found at the base of the Annona chalk at the outcrop and is represented in this area as a sandy shale, ordinarily containing little sand.

Ozan formation.—The Ozan formation, about 150 feet thick, is made up of gray marls and clay, generally finely micaceous and containing some very fine-textured sand. The Buckrange sand found at the base of the Ozan formation, a prolific oil producer in several fields in southern Arkansas, is here represented as somewhat sandy clay.

Brownstown marl.—The Brownstown marl, with a thickness ranging from 150 to 200 feet, consists principally of gray clays.

Tokio and Woodbine formations.—Below the Brownstown marl is a series of beds showing the following sequence: a few thin sand horizons in the upper part of the section; gray, somewhat sandy, fossiliferous clays in the central part, followed by well developed sands and sandstones, containing considerable volcanic ash and lignite, in the basal part. This series increases in thickness westward from 350 feet in the Falcon area to about 700 feet in Miller County. The upper part of this series is cor-

[1]T. E. Morrison, paleontologist, Humble Oil and Refining Company, oral communication.

[2]Alva C. Ellisor, "The Age and Correlation of the Chalk at White Cliff, Arkansas, with Notes on the Subsurface Correlations of Northeast Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 8 (November, 1925), pp. 1152-64.

related with the Tokio formation of Austin age, as defined by C. H. Dane.[1] The lower part of this section is probably the equivalent of the Woodbine sand, as defined by the same author. The lateral changes from the outcrop of the Tokio and Woodbine southward into this area, and the lack of definite well data, make it difficult, if not impossible, definitely to separate the sediments into distinct formations.

COMANCHE SERIES (LOWER CRETACEOUS)

Trinity formation.—In the Falcon area, more than 1,300 feet of the Trinity formation has been penetrated in deep wells.

The upper 800 feet is made up of a series of calcareous and non-calcareous, gray, brown, and green sandy clays, with a few thin beds of red clay and limestone which have yielded fossils of Glen Rose age, and some thin beds of sandstone. About 50 feet below the top of this marine section, a thin horizon of celestite was cored which is thought to represent a part of the anhydrite zone of the Glen Rose, which, in northwestern Louisiana, is 500 feet thick. The Trinity formation is separated from the overlying Gulf series by a pronounced unconformity which brings the Gulf series into contact with successively older truncated beds of Trinity age from west to east.

The beds of the lower 500 feet of dull red, light green, brown, and gray sandy clays, in part calcareous but non-fossiliferous, with subordinate beds of sands and sandstone, are generally referred to as the Lower Trinity red shale and sandstone.

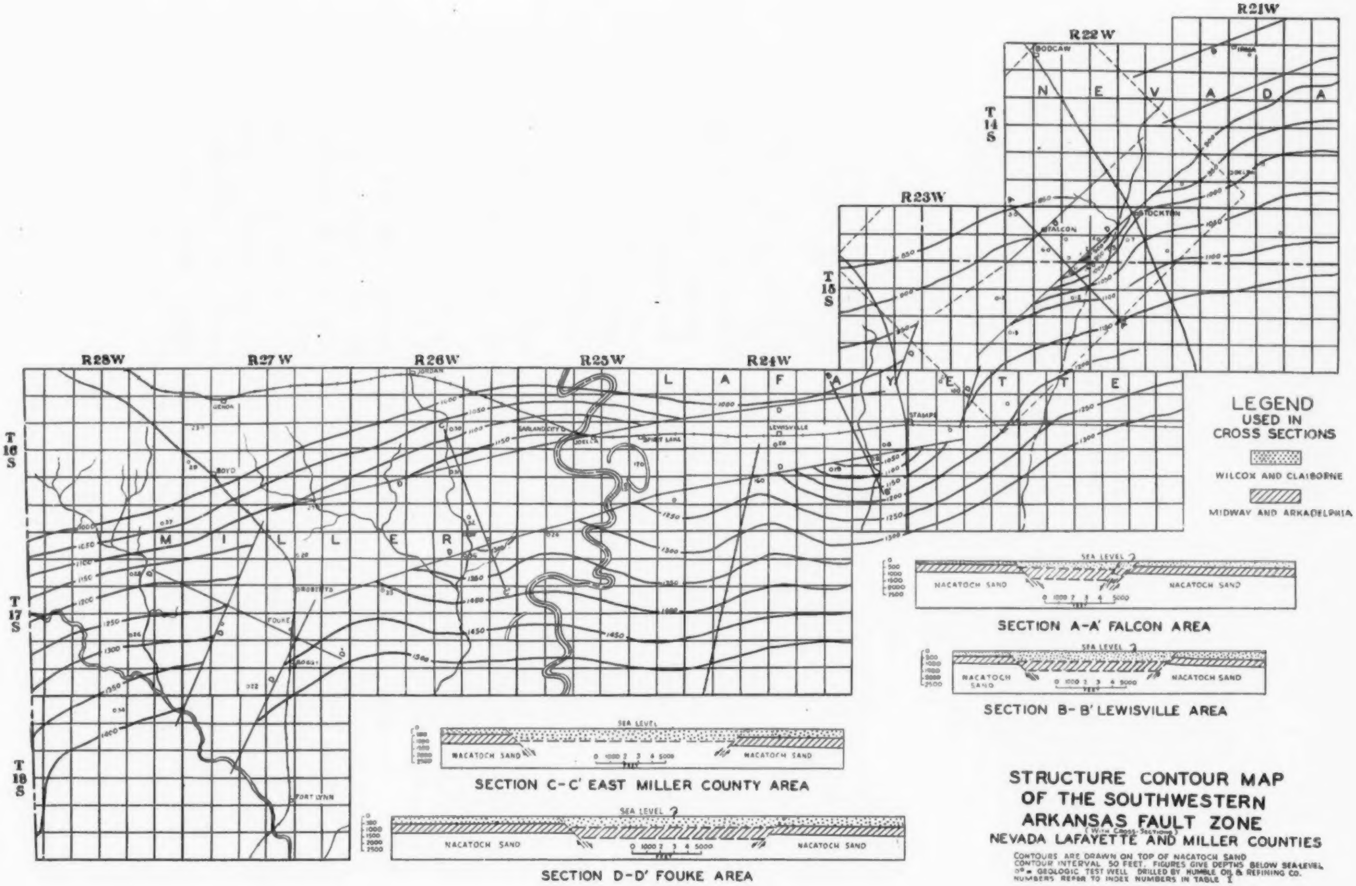
STRUCTURE

GENERAL STATEMENT

The faulted area described in this paper includes a series of nearly parallel faults which form grabens that extend for 50 miles in a general southwesterly direction from south-central Nevada County, across Lafayette County, into south-central Miller County. The width of the grabens ranges from 1½ to 3 miles and the amount of throw ranges from 300 to 400 feet. The faults bounding the grabens are not continuous, but form four distinct grabens, which from east to west, as shown in Figure 1, are referred to as Irma, Falcon, Lewisville, and Fouke. The fault planes have an average inclination of 45° with the horizontal.

In Nevada County the faults strike northeast and coincide with the Wilcox-Claiborne contact, whereas through Lafayette and Miller counties the trace of the faults gradually advances down-dip to lie wholly within the outcrop of the Claiborne formation.

[1] C. H. Dane, "Oil-Bearing Formations of Southwestern Arkansas," *U. S. Geol. Survey Press Bulletin* (September 10, 1926).



R21W
R22W
R23W
R24W
R25W
R26W
R27W
R28W
T 14 S
T 15 S
T 16 S
T 17 S
T 18 S
N E V A D A
L A F A Y E T T E
M I L L E R
BODCAW
FALCON
STOCKTON
STAMPS
LEWISVILLE
SPIRIT LAKE
JORDAN
GENOA
BOYD
FOUKE
FORT LYNN
LEGEND
USED IN
CROSS SECTIONS
WILCOX AND CLAIBORNE
MIDWAY AND ARKADELPHIA
SECTION A-A' FALCON AREA
SECTION B-B' LEWISVILLE AREA
SECTION C-C' EAST MILLER COUNTY AREA
SECTION D-D' FOUKE AREA
SEA LEVEL
NACATOCH SAND
STRUCTURE CONTOUR MAP
OF THE SOUTHWESTERN
ARKANSAS FAULT ZONE
(With Cross-Sections)
NEVADA LAFAYETTE AND MILLER COUNTIES
CONTOURS ARE DRAWN ON TOP OF NACATOCH SAND
CONTOUR INTERVAL 50 FEET. FIGURES GIVE DEPTHS BELOW SEA-LEVEL
GEOLOGIC TEST WELL DRILLED BY HUMBLE OIL & REFINING CO.
NUMBERS REFER TO INDEX NUMBERS IN TABLE I
0 1 2 3 4 5 6
SCALE IN MILES

FIG. 1

The regional dip in this area is somewhat east of south at the rate of about 50 feet to the mile.

DESCRIPTION OF GRABENS

IRMA GRABEN

The Irma fault[1] is in south-central Nevada County, Arkansas. The graben, extending 10 miles northeast and southwest, has a width of 2 miles and an average throw of 400 feet. The productive closure against the fault, based on the top of the Nacatoch sand, is about 50 feet. The course of the graben closely follows the strike of the Wilcox-Claiborne contact in a manner similar to that of the Falcon graben immediately southwest.

FALCON GRABEN

Location.—The Falcon graben, as here defined, has a width of 2 miles, extending from the vicinity of Stamps, Lafayette County, in a northeasterly direction, into southwestern Nevada County, a distance of 12 miles. The town of Falcon, located in the SW. ¼, Sec. 5, T. 15 S., R. 22 W., is near the center of the northern boundary of the graben.

Topography.—Falcon is near the center of the southern limit of an area of high, rolling sand hills of Wilcox age. The hills are 10 miles long, range from 2 to 3 miles in width, and extend northeast and southwest from the town. This sand zone serves as a drainage divide between Dorcheat Bayou on the east, and Bodcau Bayou on the west.

North and south of this zone, the lignitic sandy clays and argillaceous sands form a terrain with less relief, gradually descending to Bodcau and Dorcheat bayous, respectively.

Elevations range from 250 feet along the main drainage systems to 400 feet along the drainage divide. The average local relief is about 50 feet.

Beds exposed in Falcon area.—Table III gives a section of formations exposed in the Falcon area.

Owing to the lack of fossiliferous beds, the outcropping sediments are separated into lithologic units based chiefly upon horizons of distinctive concretions. Lateral changes in the character of the sediments limit the use of this section to a comparatively small area.

Zone D, as shown in Figure 2, represents the oldest Wilcox beds exposed in the Falcon area. The upper part is a gray sandy clay with considerable interbedded brown, lignitic, very sandy clay which down-

[1] L. P. Teas, "Irma Oil Field, Nevada County, Arkansas," *Structure of Typical American Oil Fields*, Vol. I (Amer. Assoc. Petrol. Geol., 1929), pp. 1-17.

TABLE III

SECTION OF FORMATIONS EXPOSED IN FALCON AREA

Formation	*Thickness in Feet*	*Zone*	*Character*
Quaternary	0–50		Gray and pale yellow-red sandy clays, sand, and gravel
Claiborne	400	*A*	Sandy clays and argillaceous sands in upper part. Contains thin lenses of ferruginous sandy clay with some glauconite. The gray argillaceous sand of the lower section is interbedded with horizons of gray and brown, slightly glauconitic, sandy clay. Approximately 100 feet of this lower section is exposed in the Falcon graben
Wilcox	200	*B*	Gray sand with ferruginous sand concretions ½-1 inch in diameter. A little gray clay
	50	*C*	Brown and black, lignitic, somewhat sandy clay. Many limonitic concretions
	50	*D*	Gray and brown lignitic, very sandy clay. Some sand and red ferruginous sandstone, locally quartzitic at base

ward becomes increasingly sandy and is finally represented as a dull, yellowish red and gray, argillaceous sand with a few thin beds of lignitic, very sandy clay. This lower part weathers to gray sand with small blocks of pale yellowish brown, fine-textured, somewhat indurated sandstone. Zone *D* is 50 feet thick. The basal bed of this zone is a thin horizon of gray to pink, medium-textured, quartzitic sandstone.

Zone C is made up of 50 feet of brown and black, lignitic, somewhat sandy clay containing many concretions of limonite and much weathered siderite, ranging from 12 to 18 inches in diameter, with interbedded gray sand. Near the top of the zone is a more or less definite horizon of much weathered siderite concretions about 1 foot thick, which is also present on the north side of the Irma graben. In both localities it has the same stratigraphic position in the section.

Zone B, 200 feet thick, is made up of gray and pale yellowish red, fine- to medium-textured, slightly argillaceous sand, with some gray clay. The sand contains many gray, oval to round, soft ferruginous sand concretions ranging from ½ to 1 inch in diameter. The highest part of this zone is cut out by faulting in the Falcon area and consists of a series of gray, argillaceous sands and gray and brown, very sandy clay. This upper part is without distinctive concretionary forms.

Zone A, the Claiborne section, is very poorly expressed in comparison with the section in other Claiborne areas; therefore, only a general group

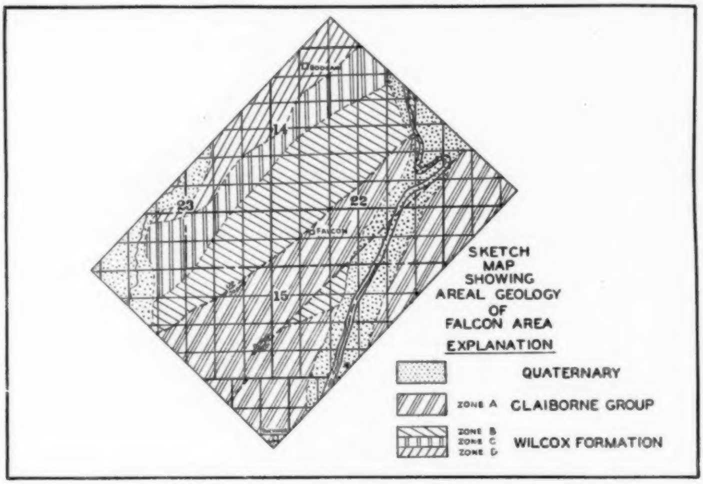


FIG. 2

correlation is attempted in the area under discussion. A small exposure of slightly glauconitic, very sandy clay in Sec. 30, T. 14 S., R. 21 W., is tentatively correlated as basal Claiborne. A few exposures of thin lenses of ferruginous sandy clay with some glauconite, found within the graben area, are believed to be a repetition of the somewhat glauconitic sandy clay beds exposed near the town of Waldo in Columbia County.

SURFACE EXPRESSION OF FALCON GRABEN

North side of graben.—The fault on the north side of the Falcon graben is bounded by the Zone *B* gray sand, in normal position, containing many ½-1-inch soft ferruginous sand concretions. Several abrupt changes in lithology from the normal sand section of Zone *B* to the brown and black lignitic clay with thin horizons of somewhat concretionary, limonitic sandstone of Zone *A*, were found along the northern fault.

In a road cut ½ mile northeast of Falcon, the fault trace is exposed trending N. 45° E. On the north side of the fault plane, pale bluish gray, somewhat sandy clay containing some volcanic ash is found in contact with yellowish red argillaceous sand. This fault is thought to have only slight displacement, being a minor break within a zone of fracture created by the major fault at Falcon. One-half mile north of the town of Falcon, a road exposure shows pale reddish yellow sand containing very irregular planes dipping 25° S. 20° E., which may indicate a zone of dis-

turbance secondary to the main Falcon fault. Another trace of the northern fault may be found on the road near the center of Sec. 22, T. 15 S., R. 23 W., where a slight lithologic difference was seen in the beds on either side of a N. 30° E.-trending fracture, dipping 85° SE. Near the northwest corner of Sec. 24, T. 14 S., R. 22 W., an outcrop of chocolate clay shows a maximum dip of 60°, which is believed to be near the northeastern limit of the north side of the graben.

Lithologic data from shallow water wells were used extensively in delineating the course of the fault alignment, especially where the surface beds were hidden by alluvium and Quaternary sand and gravel.

Water wells at the town of Falcon record weathered sand and clay to a depth of 20 feet below the surface, and black lignitic clay, correlated with the upper part of Zone *A* of the Claiborne formation, to a total depth of 66 feet. It is reported that a water well 155 feet deep, at a gin less than ¼ mile northwest of these lignitic clay wells, had sand to the bottom of the hole. Several water wells in this area, having the same elevation as the lignitic clay wells immediately southeast, at the town of Falcon, penetrated water-bearing sand from the surface to a depth of 80 feet. A water well drilled to a depth of 350 feet in Sec. 7, T. 15 S., R. 22 W., 1 mile southwest of the previously mentioned 155-foot well, records sand and soft rock for 250 feet, underlain by 150 feet of blue clay extending to the bottom of the hole. Immediately southeast of this well, black lignitic clay with limonitic, somewhat concretionary sandstone, correlated with Zone *A* of the Claiborne graben section, is found. In the SE. ¼, NE. ¼, Sec. 14, T. 15 S., R. 23 W., a considerable thickness of black lignitic clay of the graben section is present in shallow wells. This locality is less than ¼ mile southeast of the exposure of the gray sand section with ½-1-inch ferruginous sand concretions of Zone *B*. This relationship plainly marks the position of the north side of the graben at this locality.

Southern side of graben.—The southern limits of the graben are obscured to a marked degree because a considerable part of the northeastern half lies within low land along Dorcheat Bayou, whereas in the southwestern part the sharp lithologic units are not as clearly defined as at the town of Falcon. It is, furthermore, partly concealed by a mantle of Quaternary sand and gravel.

As the somewhat lignitic, sandy clays of the lower part of Zone *A* are in contact with the black, lignitic, somewhat sandy clays of the upper part of Zone *A* of the down-thrown block on this side of the graben, it is impossible to show as clear-cut a lithologic break as is found on the north

side of the graben. An alignment of a general lignitic clay-argillaceous sand break, only, was made along this section of the fault. An exposure of partly obscured, very sandy clays and sands in Secs. 16, 17, 20, and 21, T. 15 S., R. 22 W., has been tentatively correlated as the top of Zone *B*. This is the area of closure against the fault south of Falcon.

A dip of 4° S. in lignitic clay, near the northeast corner of Sec. 30, T. 14 S., R. 21 W., was taken as an expression of disturbance. It is interesting to notice that immediately southwest of this point Dorcheat Bayou swings sharply northeast, forming a sharp U-bend, and follows the fault for a distance of about 3 miles before crossing the fault to continue on its normal southwestern course.

Structure.—Surface dips have been generally considered unreliable as control in this area. Those with high angles have been thought to indicate zones of disturbance.

The faulted area described has a graben 12 miles long and nearly 2 miles wide, with a throw ranging from 300 to 400 feet, and with a closure of about 75 feet against the fault on the south side of the graben. The average regional dip is 50 feet to the mile toward the southeast. As shown in Section *A-A'* of Figure 1, the top of the Nacatoch sand is brought into contact with the shales of the Midway formation, which should effectively serve as a seal for the sand. The Nacatoch sand slopes from its crest adjacent to the fault plane, at a depth of 906 feet below sea-level, southeastward, with a possible closure of 75 feet against the fault.

Summary.—The graben of the Falcon fault is expressed at the surface by an area of black lignitic clay with limonitic concretionary sandstone, 2 miles wide and 12 miles long, striking N. 45° E. The town of Falcon is located near the center of the northwestern side of the downthrown block. The northeast end of the graben is near the Irma fault. At the southwest, it is hidden by a mantle of Quaternary sand and gravel. The section exposed in the graben is thought to be a repetition of the upper part of the Lower Claiborne formation. With the exception of the somewhat ferruginous sandy clay in the E. ½, Sec. 30, T. 14 S., R. 21 W., which may be the equivalent of the Cane River formation of Louisiana, the basal Claiborne is either missing or has been cut out by the fault.

The north side of the graben is marked by sharp lithologic breaks, fractures, and steep dips. Nearly half of the southern side is located within low lands. The pronounced lithologic break of the north side is lacking on the south side of the fault, due to beds of gray and brown sandy clay within the general argillaceous sand zone of the normal sec-

tion of Zone *B* in contact with the lignitic sandy clay of Zone *A* of the graben section.

LEWISVILLE AND FOUKE GRABENS

From the Falcon fault southwestward to Sulphur River, the terrain is mantled by Quaternary sand and gravel and alluvium, which effectively conceal the surface evidence of faulting in that area. The structural features of the Lewisville graben in the adjacent area, as shown in section *B-B′* of Figure 1, and the Fouke graben in section *D-D′* of Figure 1, are based upon well records. With the exception of a small area in Miller County, west of McKinney Bayou, no detailed reconnaissance was done in this area.

Small isolated exposures of lignitic clay and limonitic concretions occur in Secs. 20 and 21, T. 15 S., R. 24 W. Sandy clays, somewhat glauconitic, occur in railroad cuts in the vicinity of Artex, Miller County, especially in Sec. 6, T. 16 S., R. 26 W. It is thought that these outcrops may be poorly developed basal Claiborne.

Somewhat ferruginous clays are found at several places extending northeastward from the town of Boggy for a distance of about 6 miles in T. 17 S., R. 27 and 28 W. Stratigraphically these exposures are about 400 feet higher than the previously mentioned exposures; are the time equivalent of the ferruginous sandy clay zones southeast of the Falcon fault; and are about 1,700 feet above the top of the Nacatoch sand.

Small, deep reddish brown, very sandy concretions are found in orange red, very sandy clay in Sec. 3, T. 17 S., R. 27 W., approximately 1 mile north of the town of Roberts. This bed crops out within the graben, and is thought to be a repetition of the clays in the vicinity of Boggy.

OIL AND GAS SHOWINGS

Nacatoch sand.—No oil and gas showings were encountered above the Nacatoch sand. A few Nacatoch sand wells yielded showings of oil and gas on the south side of the Falcon area. The test wells drilled in the graben, with few exceptions, did not reach the Nacatoch sand, but the Humble Oil and Refining Company's Pelt No. 1, in Sec. 8, T. 15 S., R. 22 W., near the center of the Falcon graben, showed a considerable saturation of dead, heavy oil in cores from the top of the Nacatoch sand, and Steele *et al.* Pelt No. 1, in Sec. 9, T. 15 S., R. 22 W., also located in the graben, found a small accumulation of heavy oil in the top of the Nacatoch sand.

Deeper sands.—The Buckrange sand, the oil-producing horizon in the Stephens field, also very productive in the Smackover, Haynesville,

and Homer fields, in this area is represented by a fine-textured sandy shale unsuitable as a reservoir for oil and gas accumulation. The Tokio formation and the basal Upper Cretaceous contain several sands capable of serving as reservoirs for oil and gas. Sands in the Tokio-Woodbine series yielded small showings of oil and gas on the Falcon closure.

The Trinity formation, which, in this area, has a total thickness of not less than 3,000 feet, contains several sand bodies which have been in part penetrated by the Humble Oil and Refining Company's Bodcaw-Fee 4-A, where there was a showing of gas at a depth of 2,850 feet, coming from a gray, medium-textured sandstone with very calcareous cement.

CRETACEOUS AND TERTIARY SEDIMENTS OF KENTUCKY, ILLINOIS, AND MISSOURI[1]

J. E. LAMAR[2] and A. H. SUTTON[3]
Urbana, Illinois

ABSTRACT

The embayment sediments of Kentucky, Illinois, and Missouri consist of the Tuscaloosa gravel, Eutaw sand, and Ripley sand and clay of Cretaceous age, the Porters Creek clay and Lagrange sand and clay of Eocene age, and the "Lafayette" gravel and sand and the colluvium of Pliocene age. The outcrops of these sediments form an inverted U-shaped belt whose apex crosses southern Illinois and whose east and west sides lie respectively in western Kentucky and southeastern Missouri. The outer side of the U is bounded by Paleozoic strata; the center is composed largely of Pleistocene sediments and Recent deposits of Mississippi and Ohio rivers.

The outstanding features of the embayment deposits are: (1) they are almost totally unconsolidated, and (2) calcareous material is very uncommon, suggesting either deposition principally of non-calcareous sediments during Cretaceous-Tertiary times or widespread and pronounced leaching subsequent to deposition.

Lignitic strata contain a few fragmentary plant remains; animal fossils are extremely rare.

Structural data are poor, but the best available suggest a general gentle dip of the sediments toward the deeper part of the embayment, possibly with minor anticlinal folds plunging basinward in the marginal parts. Settling and creep have produced striking local deformation.

The source of the sands and clays of the embayment deposits is thought to have been principally the Pennsylvanian and upper Mississippian sandstones and shales of the adjoining parts of Illinois, Missouri, and Kentucky. The limestones in the same areas have probably also contributed to the clays. The chert gravel making up the Tuscaloosa and Lafayette formations seems to have been derived for the most part locally from cherty limestones and chert formations.

INTRODUCTION

The embayment sediments of Kentucky, Illinois, and Missouri are unique in that they represent the northernmost deposits of the gulf extension in the valley of Mississippi River proper. Their areal extent in these three states is limited and details concerning their distribution and character are not generally available. This article is a compilation of published data, revised and supplemented by unpublished field observations made by the writers.

[1]Read by title before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, March 1, 1930.

[2]Illinois State Geological Survey. Introduced by M. M. Leighton.

[3]University of Illinois. Introduced by M. M. Leighton.

Acknowledgments

The part of this article dealing with the deposits of Illinois and Missouri has been prepared by J. E. Lamar and that concerning Kentucky by A. H. Sutton. The coöperation of the Missouri Bureau of Geology and Mines, the Illinois State Geological Survey, and the Kentucky Geological Survey in furnishing data is gratefully acknowledged.

Topography

The topography of the embayment area of Kentucky, Illinois, and Missouri may be divided into three parts, (1) the uplands, whose topographic form is largely due to a core of consolidated rock, (2) the alluvial flats of Mississippi and Ohio rivers, and (3) the gently rolling flats and hill lands of the embayment sediments. The uplands form a more or less continuous scarp which marks the northernmost extent of the Cretaceous and Tertiary sediments as now found except for deposits of relatively limited extent in areas protected from erosion.

Character of Rock Floor Beneath Embayment Sediments

Little is known in detail about the rock floor on which the embayment sediments rest, except that it appears to be a spoon-shaped basin whose sides rise gently toward the scarp bounding the lowlands. From Cairo, Illinois, the rock floor rises about 40 feet per mile toward the northwest and northeast and about 45 feet per mile toward the north; in Kentucky the floor rises gently northeast, and in Missouri northwest. The greatest known depth to rock is at Bondrant, 8 miles southwest of Hickman, Kentucky, where bed rock is encountered at 2,270 feet.[1] Depths to rock at other locations are as follows: in Illinois—Cairo, 525 feet; Ullin, 160 feet; Unity, 267 feet; Mound City, 305 feet; Metropolis, 292 feet; in Kentucky—La Center, 387 feet; Wickliffe, 1,000 feet; Paducah, 335 feet; in Missouri—Morehouse, 690 feet; and Bloomfield, 430 feet.

The Paleozoic floor commonly has a topography of moderate local relief, as far as is known, except in its marginal parts, where scattered monadocks occur and well developed, steep-sided valleys cut the bedrock floor and extend back into the present uplands.

[1] W. R. Jillson, The Sixth Geological Survey, Part VII, "The Oil and Gas Possibilities of the 'Jackson Purchase' region," *Kentucky Geol. Survey*, Ser. 6, Vol. 9 (1921), p. 212.

Character of Upland Scarp

In Kentucky the upland scarp bordering the Cretaceous-Tertiary basin is composed principally of Mississippian limestones, sandstones, and shales, and has a local relief ranging from 50 to 150 feet. In Illinois the scarp is also made up of Mississippian strata, mostly limestones except in the western part, where the Clear Creek chert of Devonian age and a small area of older rocks comprise the uplands. The relief of the scarp in Illinois ranges from 60 to 150 feet. In Missouri the uplands are underlain almost exclusively by Ordovician limestones and have a relief ranging from 100 to 200 feet.

Character of Outcrops

Outcrops of the embayment sediments are relatively common in Kentucky, Illinois, and Missouri, but are ordinarily limited both horizontally and vertically except where the exposures are artificial or where rapid stream cutting has produced steep banks. Slumping obscures the details of many outcrops and the loess which mantles the uplands reduces the number and extent of the exposures. In addition to the loess, other Pleistocene deposits, mostly sands and gravels, are found locally, but are generally of insufficient extent to interfere greatly with the studies of the older unconsolidated sediments.

Geologic Column

The succession of Upper Cretaceous and later sediments found in Kentucky, Illinois, and Missouri corresponds well with that described by Glenn[1] and Nelson[2] for Tennessee, and by Call[3] for northeastern Arkansas. The stratigraphic sequence is indicated in Table I.

Description of Formations

INTRODUCTION

One of the outstanding features of the Cretaceous and Tertiary sediments of Kentucky, Illinois, and Missouri is the general absence of fossils and calcareous material. Only one marine fossil is known from

[1]L. C. Glenn, "Underground Waters of Tennessee and Kentucky West of Tennessee River and of an Adjacent Area in Illinois," *U. S. Geol. Survey Water-Supply and Irrigation Paper 164* (1906).

[2]W. A. Nelson, "Clay Deposits of Tennessee," *Tennessee Geol. Survey Bull. 5* (1911), p. 9.

[3]R. Ellsworth Call, "The Geology of Crowley's Ridge," *Arkansas Geol. Survey Ann. Rept. for 1889*, Vol. II (1891).

TABLE I

SUBDIVISION OF UPPER CRETACEOUS AND TERTIARY SEDIMENTS OF KENTUCKY, ILLINOIS, AND MISSOURI

- Cenozoic group
  - Tertiary sub-group
    - Pliocene system
      - Colluvium
      - "Lafayette" gravel and sand
    - Eocene system
      - Lagrange sand and clay
      - Porters Creek clay
- Mesozoic group
  - Cretaceous system
    - Upper Cretaceous series
      - Ripley sand and clay
      - Eutaw sand and clay
      - Tuscaloosa gravel and sand
- Paleozoic sediments (bed rock)

Illinois, namely, *Exogyra cancellata*,[1] a Ripley form which was found in an excavation at Cairo well below the zone of leaching. One very poorly preserved specimen suggestive of *Inoceramus* is reported from the Tuscaloosa formation of Kentucky. Some of the dark-colored clays and lignitic strata of the Ripley and Lagrange formations contain plant remains.

The only calcareous strata known in outcrop are in Kentucky, where a few inches of calcareous sandstone is found locally in the base of the Porters Creek formation. The calcareous material seems to have come from calcareous fossils whose casts may be seen in the overlying clay beds. No calcareous sediments of any kind are exposed in Illinois nor have any been reported from Missouri. However, wells drilled in Ballard County, Kentucky,[2] are said to have encountered marls in both the Ripley and Lagrange formations.

Notwithstanding the lack of calcareous material, in view of the fact that the uplands bordering the embayment sediments are composed largely of limestone, it seems improbable that entirely non-calcareous sediments could have been deposited throughout Cretaceous, Eocene, and Pliocene times. The alternative hypothesis that the original calcium carbonate present has been removed by leaching seems, therefore, to be the more feasible explanation of the phenomenon, and is substantiated

[1] L. W. Stephenson, "Cretaceous Deposits of the Eastern Gulf Region and Species of *Exogyra* from the Eastern Gulf Region and the Carolinas," *U. S. Geol. Survey Prof. Paper 81* (1914), p. 55.

[2] W. R. Jillson, *op. cit.*, p. 211.

by the fossil casts previously mentioned and by the reported occurrence of marl beds below the zone of leaching.

CRETACEOUS SYSTEM

TUSCALOOSA FORMATION

Distribution.—The general areal distribution of the Tuscaloosa gravels is shown in Figure 1. Their only known occurrence is in Kentucky; they are found only in small separated areas adjacent to Cumberland River, and are not known west or south of Tennessee River. Some of the best exposures are in the vicinity of Grand Rivers, where the formation is more than 100 feet thick.

One of the outstanding features of the Tuscaloosa formation is that it occurs very commonly on the sides of the hills and seems to represent near-shore deposition in a sea which did not completely submerge the region.

Lithologic character.—The Tuscaloosa gravel is composed largely of well rounded white or gray chert pebbles which are locally cemented to conglomerate by either an iron oxide or a silica cement. In places the formation contains beds of sand, sandstone, and lenses of white siliceous clay.

Thickness.—Because of the mode of occurrence of the Tuscaloosa gravels and the effects of differential erosion, it is difficult to determine the thickness of this formation. The best data available, however, suggest a thickness ranging from a few inches to 170 feet. The maximum at Grand Rivers is 120 feet; other thick deposits are present in the same region. The formation thins toward the north and only 25 feet is reported at Smithland. Toward the south the thickness increases, becoming as much as 170 feet in Trigg County, Kentucky.

Stratigraphic relations.—The contact of the Tuscaloosa with the underlying Paleozoic sediments represents a great erosional unconformity. The gravels are in contact with strata ranging from the St. Louis limestone of Lower Mississippian age to the Pottsville sediments of Pennsylvanian age.

Except in the extreme southeastern part of the embayment area in Kentucky, where Eutaw sands occur, the Tuscaloosa is ordinarily unconformably overlain by the Ripley formation, but in some places it is unconformably overlain by Lafayette and Recent sediments.

Correlation.—The Tuscaloosa gravel of Kentucky is correlated with that of the type locality on the basis of a practical continuity of outcrops

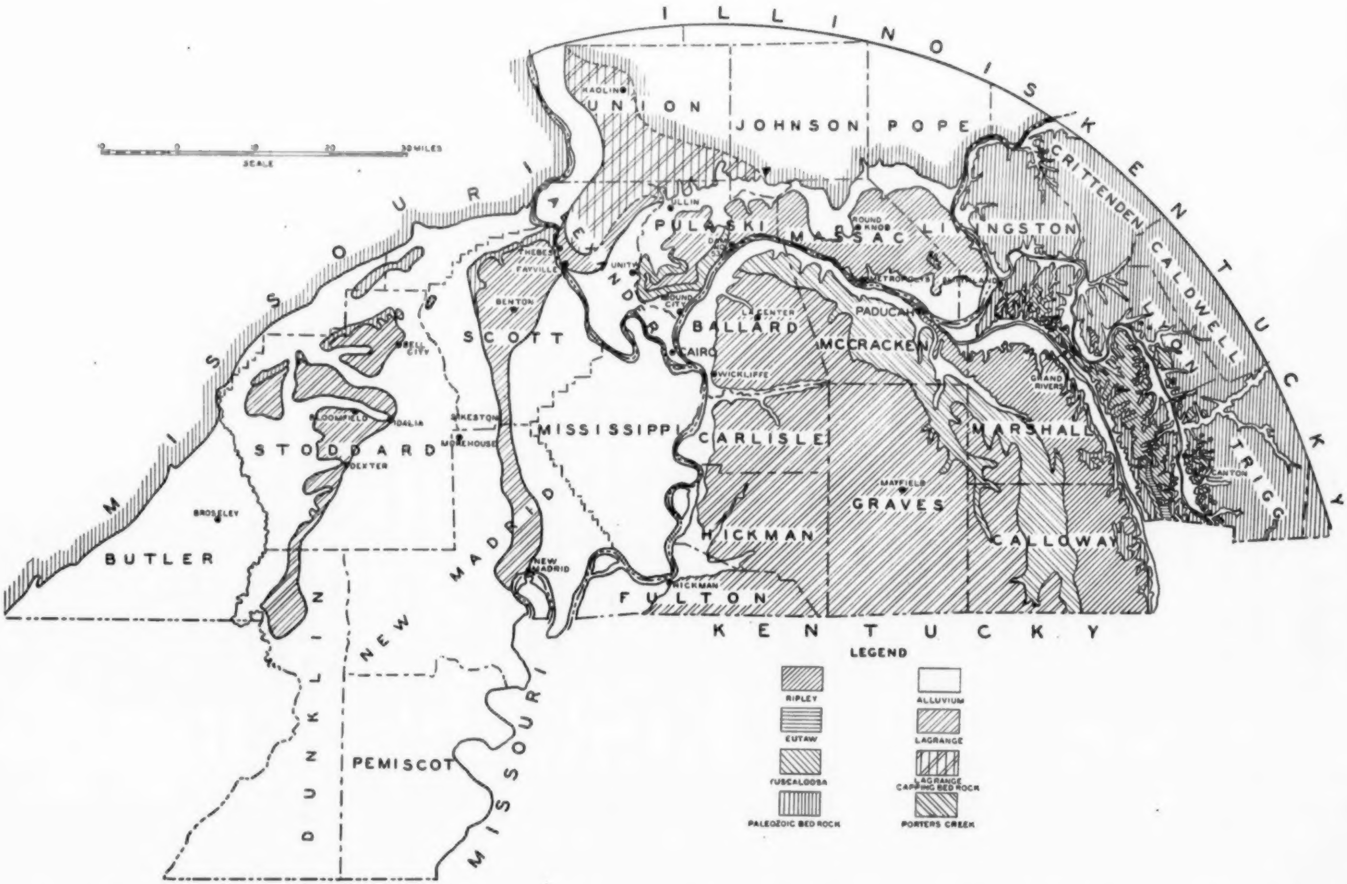


FIG. 1.—Geologic map showing the distribution of Cretaceous and Eocene sediments in Kentucky, Illinois, and Missouri. Compiled from geologic maps of Kentucky and Missouri, and map (Fig. 5) from D. H. Davis' "Geography of the Jackson Purchase," *Kentucky Geol. Survey*, Ser. 6, Vol. 9 (1923), and modified by unpublished data.

from the one place to the other. Wade[1] seems to have been the first worker definitely to apply the name Tuscaloosa to the gravels of Kentucky.

EUTAW FORMATION

Distribution.—The Eutaw formation is known in only one locality in the northern part of the embayment region, namely, the western part of Kentucky, where it occurs on the ridge tops between Cumberland and Tennessee rivers. It occupies a narrow area—about a mile wide—and extends into Kentucky from Tennessee for a distance of about 12 miles.

Lithologic character.—The Eutaw formation is composed chiefly of fine- to medium-grained sands and subordinate amounts of clays of various colors. The sands and clays intergrade laterally and indicate deposition in shallow water with continually changing currents. Much of the sediment is cross-bedded.

Thickness.—The Eutaw formation in Kentucky is thin, being less than 40 feet thick in any of its exposures.

Correlation.—This formation is the equivalent of the Coffee sands of Safford, and according to Glenn[2] is thought not to include any beds equivalent to the Tombigbee sand of the upper part of the type Eutaw.

RIPLEY FORMATION

Distribution.—The Ripley formation is represented in Kentucky, Illinois, and Missouri, so far as is known, only by the McNairy sand member, which crops out as a narrow band extending nearly northwest and southeast through Kentucky and in Massac County, Illinois (Fig. 1). West of this outcrop area the formation dips beneath younger beds and is not known to appear at the surface elsewhere in the area under discussion. Sediments thought to be Ripley in age are encountered, however, in several wells in Missouri at depths ranging from about 300 to 500 feet.

Lithologic character.—The Ripley formation is composed dominantly of sand, for the most part medium- to fine-grained, and angular. The exposed sand is ordinarily yellow to brown, but white and pink sands are not rare. In wells the unoxidized sand is commonly medium or dark gray. Locally the sand is sufficiently cemented to be called a sandstone, but in general it is unconsolidated. In the Missouri well records the formation is commonly reported as fine or quick sand, probably synonymous

[1]Bruce Wade, "The Occurrence of the Tuscaloosa Formation as Far North as Kentucky," *Johns Hopkins Univ. Cir.*, n. s., No. 3 (1917), pp. 102-06.

[2]L. C. Glenn, "Underground Waters of Tennessee and Kentucky West of Tennessee River and of an Adjacent Area in Illinois," *U. S. Geol. Survey Water Supply and Irrigation Paper 164* (1906), p. 23.

terms. Good outcrops of the Ripley may be seen south of Smithland, Kentucky, and at Dam 53, Illinois, on Ohio River.

Clay, either as distinct beds or as thin layers interstratified with sand, is more or less common throughout the entire formation, but is more common in the lower beds exposed than in the upper strata. The clays are gray, white, pink, or bluish, and locally contain lignite. The thicker strata are commonly sandy and locally reach a maximum thickness of 20 feet. These clays are well exposed in the vicinity of Round Knob, Illinois, and about 4½ miles northeast of Grand Rivers, Kentucky.

Thickness.—In Kentucky the exposed thickness of the Ripley sediments ranges from a few inches to about 100 feet, the maximum thickness being found south of Tennessee River in the Smithland area. The greatest thickness recorded in wells was encountered at Wickliffe, Kentucky, where 400 feet of Ripley was penetrated. In Illinois the maximum exposed thickness is 70 feet at Dam 53 on Ohio River. At this place a well was drilled through an additional 200 feet of sediments which are probably Ripley in age.

Stratigraphic relations.—The Ripley sediments are unconformable with the underlying Tuscaloosa or Eutaw formation and probably also with the overlying Porters Creek. Glauconite is commonly associated with the upper contact. Where the Porters Creek formation is absent the Ripley is ordinarily overlain by Lafayette or Recent sediments (Fig. 2).

FIG. 2.—Contact of Ripley clay with overlying Lafayette gravel at Iron Hill, 4½ miles northeast of Grand Rivers, Kentucky.

Paleontology.—The only Ripley fossil known is a pelecypod, *Exogyra cancellata*, reported by Stephenson,[1] from material removed from an excavation in Cairo. It is considered to be a Cretaceous form, but, as the Ripley formation lies at a depth of about 500 feet in the Cairo region, it seems probable that the fossil was found in a re-worked deposit of comparatively recent origin.

Correlation.—The Ripley beds of Illinois and Kentucky may be traced southward to the type locality in Mississippi, and on this basis are correlated with the type beds.[2]

EOCENE SYSTEM

PORTERS CREEK FORMATION

Distribution.—The Porters Creek formation crops out as a northwest-southeast belt having a maximum width of 12 miles in Calloway County, Kentucky (Fig. 1). Toward the northwest the width of the area of outcrop decreases and in Illinois it rarely exceeds 3 miles. West from Pulaski County, Illinois, the formation dips below younger sediments and is not known to occur elsewhere at the surface unless the gray clay reported at Idalia and Bloomfield, Missouri, is Porters Creek—a conclusion which a study of well records of the region seems to justify. The Porters Creek is widespread in the embayment area and seems to form a continuous bed beneath the basin.

Lithologic character.—The outstanding characteristic of the Porters Creek where exposed in Illinois and Kentucky is that, when fresh, it is dominantly a hard, dark gray clay. Much of it does not readily become plastic when wet; consequently, the formation stands in steeper faces than is ordinarily normal for clay. Weathering commonly changes the dark gray color to buff or creamy white, but plasticity is developed ordinarily only in places where the drainage is poor. In Illinois the upper part of the Porters Creek is the source of fuller's earth.[3] It has a characteristic fracture which produces concave chips somewhat like the hulls of hickory nuts.

The formation is mostly clay, but contains interbedded layers of fine sand, especially in its extreme upper and lower parts. The basal

[1] L. W. Stephenson, *op. cit.*, p. 55.

[2] A. M. Miller, "Geology of Kentucky," *Kentucky Geol. Survey Bull. 2*, Ser. 5 (1919), p. 165.
D. H. Davis, "Geography of Jackson Purchase," *Kentucky Geol. Survey*, Ser. 6, Vol. 9 (1923), p. 13.

[3] J. E. Lamar, "Preliminary Report on the Fuller's Earth of Pulaski County" *Illinois State Geol. Survey Rept. of Investigations 15* (1928).

part also includes glauconitic sands which locally contain sufficient calcium carbonate to cement them to an impure limestone. According to Glenn,[1] this material has come from "marine shells, the hollow impressions of which are abundant in some of the more calcareous beds." These calcareous beds are not known to occur in Illinois, but Glenn reports them as far north in Kentucky as Paducah.

Another local feature of the Porters Creek formation in Kentucky is the occurrence of sandstone dikes which penetrate the main body of gray clay. These dikes range in width from a fraction of an inch to 2 feet and are composed of very fine sand similar to the sand commonly found in the formation. In places they contain casts of marine invertebrates. Some of the openings intruded by these dikes seem to have been the result of faulting, but in general they are thought to be injections of mobile water-wet sand into fissures formed in the clay by earthquakes occurring shortly after the deposition of the clay.[2]

Thickness.—The thickness of the Porters Creek formation is variable. In the deeper parts of the embayment, as at Hickman and Bondrant, Kentucky, it seems to be respectively 470 and 480 feet thick, but near the margins of the embayment it is thinner. Near Broseley, Missouri, it is 175 feet thick; at Morehouse, in the same state, 265 feet; at Cairo, Illinois, 124 feet; and at Wickliffe, Kentucky, 155 feet.

Stratigraphic relations.—As already stated, the Porters Creek formation rests unconformably on the Ripley sediments. The character of the contact between the Porters Creek and the overlying Lagrange formation is not definitely known, but it is probably unconformable.

Paleontology.—The Porters Creek in Illinois and Kentucky locally contains indistinct marine invertebrate casts, but they are too poorly preserved to be specifically identified.

Correlation.—The Porters Creek of Illinois and Kentucky is correlated with that of Tennessee on the basis of practically continuous outcrops in the three states.

LAGRANGE FORMATION

Distribution.—The Lagrange formation is one of the two most widely distributed embayment sediments in Kentucky, Illinois, and Missouri (Fig. 1). In all three states the Lagrange sediments overlie older Ter-

[1] L. C. Glenn, "Underground Waters of Tennessee and Kentucky, West of Tennessee River, and of an Adjacent Area in Illinois," *U. S. Geol. Survey Water Supply Paper 164* (1906), p. 30.

[2] *Ibid.*, p. 31.

tiary strata and are also found resting on bed rock at considerable elevations above the general level of the embayment deposits. The distribution of the Lagrange sediments indicates that the formation was once much more extensive than it is to-day.

Lithologic character.—The Lagrange formation is composed dominantly of sand and to a less extent of clay and gravel. The clays occur principally as lenses, some of relatively large size, within sand bodies. Glenn[1] suggests that in Kentucky the Lagrange is characterized by white plastic clays in its basal part, with dark-colored, lignitic clays in many places common in the upper part, but finds that this section can not be consistently recognized. A similar subdivision is suggested in the outcrops of the western Illinois and eastern Missouri parts of the embayment area, but the character and topographic position of the exposures does not permit a thorough evaluation of the extent of this relation. It seems probable, however, that further detailed study of the Lagrange sediments will reveal possible subdivisions.

The clays of the lower part of the Lagrange are ordinarily very fine-grained, non-gritty, and highly plastic. Many of them are gray or white, but others are delicate shades of pink or green. Clays, possibly a part of the lower Lagrange, are mined at Mountain Glen, Illinois, where they have been preserved from erosion in sink holes in the underlying Mississippian limestones. At this place a shaft penetrated 87 feet of pink and white clay.[2] Orange sands are commonly associated with the clays which are locally lignitic.

Similar clay deposits are present in the eastern part of the outcrop area of the Lagrange in Kentucky.

Clays ascribed to the Lagrange,[3] probably either the lower part or the dark gray upper phase described later, are also exposed near Idalia and Bloomfield, Missouri, in Crowleys Ridge. These clays have been called the Idalia shale by Marbut,[4] who describes the clay as "uniformly dark in color, and where freshly exposed, it is black, very much resembling the dark shales of the Coal Measures." About 60 feet of this clay is exposed near Idalia, and the same clay bed is said to be present in Ar-

[1] L. C. Glenn, *op. cit.*, p. 34.

[2] C. W. Parmelee and C. R. Schroyer, "Further Investigations of Illinois Fire Clays," *Illinois State Geol. Survey Bull. 38-D* (1921), p. 46.

[3] M. E. Wilson, "The Occurrence of Oil and Gas in Missouri," *Missouri Bur. Geol. and Mines*, Vol. 16, 2nd ser. (1922), p. 263.
Wilson describes the sediments in the Missouri part of Crowleys Ridge as Wilcox and Lafayette. The Wilcox is considered a part of the Lagrange in the present article.

[4] C. F. Marbut, "The Evolution of the Northern Part of the Lowlands of Southeastern Missouri," *Univ. of Missouri Studies*, Vol. 1, No. 3 (July, 1902), pp. 21-23.

kansas, where it underlies a considerable portion of Crowleys Ridge.[1] As previously stated, it is thought that the gray clay exposed at Idalia and Bloomfield may be the upper part of the Porters Creek formation instead of one of the Lagrange clays.

The upper clays of the Lagrange are commonly dark gray, siliceous, and lignitic, and locally contain fossil plants. They are well exposed at Hickman and Wickliffe, Kentucky. A boring at the latter place penetrated more than 130 feet of dark gray clay, beginning at the surface, most of which is thought to be the upper Lagrange. Exposures thought to be the upper gray clays of the Lagrange were also seen near Fayville, Illinois.

Sands are widely distributed throughout the Lagrange formation, but are most common in the middle part. They are generally fine- to medium-grained, angular, and white, pink, brown, red, or yellow. Locally lignitic, gray or black sands are present. The sands are well exposed in Crowleys Ridge and associated ridges in Missouri, especially near Benton, from which place Marbut gave them the name of "Benton" sands.[2] These sands are also well exposed in the Fayville area of Illinois and in many places in Kentucky.

Thickness.—The thickness of the Lagrange, as known from outcrops, is variable; perhaps the greatest thickness exposed is near Dexter, Missouri, where the formation is said to be 200 feet thick. Well records, however, show greater thicknesses. At Cairo, Illinois, 100-325 feet of Lagrange sediments is reported; at Wickliffe, Kentucky, 430 feet was penetrated; and at Bondrant, Kentucky, 8 miles southwest of Hickman, 1,000 feet of sand, probably Lagrange, was encountered.

Stratigraphic relations.—The character of the contact of the Lagrange with the underlying Porters Creek in Kentucky, Illinois, and Missouri is not definitely known, although it is probably unconformable.[3] The stratigraphic relations with the Lafayette are also unconformable, although where the upper part of the Lagrange and the lower part of the Lafayette are both sandy, the line of demarcation between them is rarely determinable.

Paleontology.—Plant remains are fairly common in the upper gray clay of the Lagrange at Hickman and Wickliffe, Kentucky. A collection

[1] R. E. Call, *op. cit.*, p. 114.

[2] C. F. Marbut, *op. cit.*, p. 23.

[3] E. W. Berry, "Erosion Intervals in the Eocene of the Mississippian Embayment," *U. S. Geol. Survey Prof. Paper 95-F* (1915), pp. 74-82.

from Wickliffe contained two varieties of *Salix* (willow), four of *Quercus* (oak), two of *Sapindus* (soap berry), one of *Myrica* (bayberry), and one of *Eucalyptus*.[1]

Fragmentary plant remains have also been found at Fayville and Mountain Glen, Illinois, but no identification of them has been attempted and they are probably too poorly preserved to yield many data of value. At the former place the cast of a brachiopod was also noticed in one of the dark clays.

Correlation.—The Lagrange formation of Illinois, Missouri, and Kentucky is correlated with that of the type locality at Lagrange, Tennessee, on the basis of lithologic similarity and general continuity of the outcrop. As used in this article, the term includes the Holly Springs, Grenada, and Jackson formations of Jillson[2] and the Wilcox, Claiborne, and Jackson of Berry,[3] although the last two formations may be very poorly represented.

PLIOCENE SEDIMENTS

LAFAYETTE FORMATION

Distribution.—The Lafayette formation is the most widespread of the Tertiary deposits found in the upper part of the gulf embayment, and caps practically every large divide and ridge in the area. In many places, however, slumping and sliding have occurred; hence Lafayette sediments are found here and there, well down the slopes of the higher areas. Because of its irregular, "patchy" distribution the Lafayette is not shown on the geologic map (Fig. 1).

The extent of the Lafayette formation was evidently much greater formerly than it is now, for outlying deposits of sand and gravel of this age are found near the top of the Mississippi River bluffs in Calhoun and Adams counties, Illinois, more than 200 miles northwest of the main body of Lafayette sediments in southern Illinois. Additional data for the region north of Adams County and the adjoining area of Missouri will probably show a still further northward extension of these deposits, but, so far as is known at present, their northward extension is confined to the territory adjoining Mississippi and Illinois rivers.

[1] L. C. Glenn, *op. cit.*, p. 38.

[2] W. R. Jillson, Geologic Map of Kentucky, *Kentucky Geol. Survey*, Ser. 6 (1929).

[3] E. W. Berry, "Erosion Intervals in the Eocene of the Mississippi Embayment," *U. S. Geol. Survey Prof. Paper 95-F* (1915), pp. 74-82.

Lithologic character.—Characteristically the Lafayette has two phases, a lower gravel phase and an upper sand phase. In Kentucky about 75 per cent of the gravel is bronze-colored chert. The remainder is principally gray quartzite and smaller amounts of pink or white vein quartz pebbles. The pebbles as a whole are well rounded and unweathered.

In Illinois the Lafayette is composed predominantly of brown chert pebbles which constitute 80-90 per cent of the gravel. The remaining 10-20 per cent is made up of quartz and a few quartzite pebbles. The quartzite pebbles are ordinarily pinkish or purplish, well rounded, and somewhat larger than the remainder of the gravel; cobbles of quartzite 6 or 8 inches in maximum dimensions have been found in several places. Locally in Illinois there are also deposits composed almost exclusively of dark gray, almost black, chert pebbles which are ordinarily smaller than the bronze chert pebbles.

The composition of the Lafayette formation in Missouri is nearly the same as that in Illinois. Marbut[1] describes it as composed of 80 per cent or more of moderately well rounded, brown chert pebbles. The remainder of the gravel is made up of black, fine-grained quartzite, a little reddish quartzite, and white quartz pebbles, all thoroughly water-worn and quite unlike anything in the adjacent river valleys.

Sand and red ferruginous clay are ordinarily included with the gravel. In some deposits this fine material almost fills the voids between the gravel pebbles; in others there is a striking absence of interstitial filling. Studies of the sand associated with the gravel at Metropolis, Illinois, indicate that at that place about 50 per cent is made up of small chert fragments and 50 per cent of quartz grains.

Most of the sand strata of the Lafayette are brightly colored,—orange, red, pink, and even purple. The sand is mostly medium- to coarse-grained, but in places, as at Fayville, Illinois, it is made up largely of clear, angular quartz grains $^1/_{16}$-$^1/_4$ inch in diameter.

The gravel of the Lafayette in many places is cemented by iron oxide into a resistant conglomerate. Similarly the sand is cemented to sandstone; a silica-cemented sandstone is also present locally.

Because the Lafayette deposits are generally slumped, it is in many places difficult to differentiate between original and re-worked deposits. Some of these re-worked deposits, both in Illinois and Kentucky, attain considerable size and are exploited on a relatively large scale, as at Metropolis, Illinois.

[1] C. F. Marbut, *op. cit.*, pp. 27-28.

Thickness.—The thickness of the Lafayette formation ranges from about 20 to 65 feet and is probably generally somewhat less in Illinois than in Kentucky and Missouri. Most of the outlying deposits associated with Mississippi and Illinois rivers are thin,—between 10 and 20 feet thick.

Stratigraphic relations.—The Lafayette is unconformable with the underlying formations, but grades more or less conformably into the overlying colluvium.

Correlation.—The Lafayette gravels and sands are correlated with those of Arkansas and Tennessee on the basis of general lithologic similarity, mode of occurrence, and continuity of outcrop.

COLLUVIUM

Distribution.—Lying above the Lafayette gravel, or in limited areas overlying the Ripley, and below the loess in Illinois and Kentucky and probably Missouri, there is locally a deposit of sandy, red, very sticky clay, which is similar to the material in Mississippi called colluvium by Shaw[1] (Fig. 3). This material is evidently the result of the weathering of the underlying formation. In this area it was formed during the time subsequent to the deposition of the Lafayette gravel and preceding the deposition of the loess. Locally it contains sandstone fragments.

Thickness.—The best exposures of colluvium were noticed at Round Knob, Illinois, and in the Smithland, Kentucky, area. In the former locality its thickness ranges from a few inches to a maximum of about 6 feet. Similar thicknesses are found in Kentucky.

Stratigraphic relations.—The colluvium overlies the Lafayette conformably, and also grades upward into the loess.

Correlation.—The colluvium of the upper part of the embayment is correlated with that of the type locality on the basis of similar lithologic character and topographic position.

CONGLOMERATE OF INDEFINITE AGE

On the upper slopes of the hills near Elco, about 5 miles northwest of Ullin, Illinois, occur large slumped masses of cemented gravel which have come from a parent ledge whose position is evidently not far above the bed-rock cores of the hills. The gravel consists almost exclusively of rounded, well sorted, white and gray chert pebbles, rarely more than 1½ inches in diameter, firmly cemented by silica. The bed is probably about 5 feet thick.

[1] E. W. Shaw, "The Pliocene History of Northern and Central Mississippi," *U. S. Geol. Survey Prof. Paper 108-H* (1918), p. 142.

FIG. 3.—Red sandy clay, thought to be colluvium, near Round Knob, Illinois. The colluvium (marked by hammer) is overlain by loess and underlain by Lafayette gravel and Ripley sand.

The age of this cemented conglomerate is not known, for it was not observed associated with any Cretaceous or Tertiary sediments which might give a clue to its stratigraphic position; yet it does not seem to belong to the bed-rock formations. It is tentatively suggested as the most reasonable correlation at present that this conglomerate may be a remnant of a much thinned northern phase of the Tuscaloosa formation.

Structure

GENERAL STRUCTURE

It is difficult to select a key bed in the Cretaceous or Tertiary sediments of Missouri, Illinois, or Kentucky, of sufficient lateral extent to yield structural data of more than local significance. Of the horizons available, however, the base of the Porters Creek clay seems to be the most easily recognized and most reliable, although the base is an unconformable surface and the formation thickens notably basinward.

Insufficient data do not permit the preparation of a structure map, but the information available indicates (1) a gradual slope of the Porters Creek formation from the margins toward the deepest part of the basin, which seems to be in the vicinity of New Madrid, Missouri, and (2) two broad, flat, anticlinal noses extending and plunging basinward, one in western Pulaski County, Illinois, and the other in Stoddard County, Missouri.

SETTLING AND CREEP

A striking feature shown in many of the cuts through hills of Upper Cretaceous and later sediments is the deformation of the sediments into approximate parallelism with the present slopes of the hills. This is true not only in small hills a few hundred feet across, but also in large hills 2,000 feet in cross section, and was noticed at many places in Illinois and Kentucky. This widespread distortion is thought to have been caused by settling and creep of the sediments, when they were water-soaked, in response to gravitational forces induced by the slope of the rock floor on which they rest, or by relief developed in the unconsolidated sediments themselves. When wet, the Cretaceous-Tertiary sands and clays are very plastic and very mobile; therefore, they are able to move on a slope of low gradient. As the contour of the bed-rock surface, although known to be irregular, is rarely known in detail, it is impossible fully to interpret the precise mechanics of the creeping.

The time when the creeping and settling occurred may be dated approximately from the colluvium which overlies the older sediments unconformably and seemingly was not deformed at the same time as the underlying beds (Fig. 4). Rather, its upper surface corresponds with the general contour of the present hill surface, and its departure from horizontality probably indicates the amount of creep and settling which has occurred since its formation. The maximum creeping and settling, therefore, seems to have taken place in Pliocene or pre-Pliocene time, before the development of the colluvium.

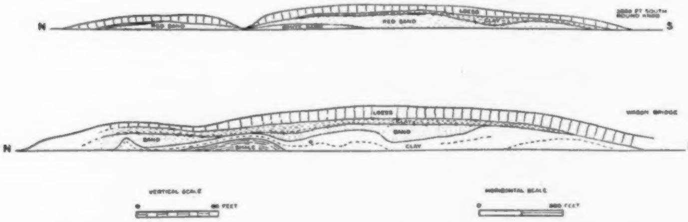


FIG. 4.—Diagrammatic cross sections illustrating typical deformation thought to be due to settling and creep. The clay beneath the loess is colluvium and is underlain by a thin pebble band representing the Lafayette formation and by Ripley sediments. The upper section is drawn from an exposure in a railroad cut west of Round Knob, Illinois; the lower from a cut north of Round Knob.

CONDITIONS OF DEPOSITION AND ORIGIN OF SEDIMENTS

In discussing the conditions of sedimentation and origin of the embayment sediments of Kentucky, Illinois, and Missouri, it is proposed to consider as units (1) the Ripley and Lagrange, (2) the Porters Creek, (3) the Tuscaloosa and Lafayette, and (4) the colluvium. The Eutaw formation is not discussed because no data are available concerning it.

RIPLEY AND LAGRANGE SEDIMENTS

The sands and clays of the Ripley and Lagrange formations were deposited in a shallow sea, probably of slack water, in which conditions of sedimentation were continually changing. The deposits are probably principally marine, although the presence of oak and other leaves in the Ripley formation in the central part of the basin may indicate local terrestrial conditions. The land areas from which the Ripley and Lagrange sediments came were evidently low. The streams were relatively sluggish and carried principally fine sediments, although in flood season some coarse materials were transported.

The sands of these two formations are thought to have been derived from the Pennsylvanian and Chester sandstones of the surrounding region. At least 500-1,500 feet of upper Pennsylvanian sediments, which are about 50 per cent sandstone, and great thicknesses of the Pottsville formation, which is about 75 per cent sandstone, have been eroded from a large area of southern and central Illinois, northeastern Missouri, and Kentucky. In addition, 500-1,000 feet of Chester sediments, which are about one-third sand, have also been partly or wholly removed from a considerable area. There was evidently, therefore, plentiful source

material available locally for the formation of the embayment sediments in the area. In accordance with this idea it is to be noticed that both the Pennsylvanian and Chester sandstones and the Ripley and Lagrange sands are commonly micaceous and are ordinarily composed of angular, unfrosted grains.

The assistance of heavy mineral data in determining the source of the later sediments is available only for Illinois. Analyses[1] of six samples of Ripley and ten samples of Lagrange sands from southern Illinois gave the following heavy minerals, not including unidentified black and white opaque minerals.

HEAVY MINERALS IN RIPLEY AND LAGRANGE FORMATIONS OF SOUTHERN ILLINOIS, LISTED IN THE ORDER OF THEIR QUANTITY

Ripley	*Lagrange*
Zircon	Zircon
Staurolite	Staurolite
Kyanite	Kyanite
Rutile	Tourmaline
Tourmaline	Rutile
Andalusite	Andalusite

The average heavy mineral content of the Ripley samples is 0.85 per cent and that of the Lagrange 0.79 per cent. In general the kyanite and staurolite grains were larger than the zircon, rutile, and tourmaline.

Comprehensive studies, made by the Illinois Geological Survey, of the heavy minerals of the Chester sandstones, failed to reveal any staurolite or kyanite grains in these sediments, although zircon, rutile, and tourmaline are common. Similar but more limited studies revealed only a few grains of staurolite or kyanite in the Pennsylvanian rocks, although tourmaline and zircon are common. Inasmuch as kyanite, staurolite, and andalusite are minerals derived from metamorphic rocks, it seems that, until full details concerning the heavy mineral content of the sediments bordering the embayment in Illinois, Kentucky, and Missouri are known, the possibility of the importation of some of the Lagrange and Ripley sands from metamorphic areas remote from the immediate region of the embayment must be borne in mind.

The clays of the formations under discussion also seem to have been derived largely from the area adjacent to the embayment. The Pennsylvanian sediments previously mentioned were probably 35-50 per cent shale, and the Chester sediments 20-30 per cent shale, providing plentiful source material.

[1]C. E. Dutton, "A Sedimentation Study of the Cretaceous-Tertiary sands of Southern Illinois," *University of Illinois Dept. Geol. Master's Thesis* (1928).

A further source of a relatively small amount of clay was probably the residual clay that resulted from the weathering of the Chester and lower Mississippian limestones. This residual clay ordinarily has a pronounced red color and probably was the source of the color in some of the pink clays present in the Ripley and Lagrange formations. Some of the red clay found with the sands may also have a similar origin.

PORTERS CREEK SEDIMENTS

The period of deposition represented by the Porters Creek clay was the longest period of Cretaceous-Tertiary time during which conditions of sedimentation and sources of material remained constant in the area under discussion. The lands were seemingly low and the streams flowing from them were sluggish; therefore, large amounts of argillaceous material and small amounts of fine sand and mica were carried into the Porters Creek sea. The sea was evidently widespread, for the clay deposited in it seems to underlie the entire upper part of the embayment area.

The sources of the Porters Creek clay seem to have been the same as the sources of the clays of the Lagrange and Ripley formations.

TUSCALOOSA AND LAFAYETTE SEDIMENTS

The Tuscaloosa and Lafayette formations are principally gravel and coarse sand; they therefore probably represent deposition in shallow water by rapidly moving streams and currents. During the preceding periods erosion had been gentle and had removed only the finer residuum from the surrounding lands. At the beginning of Tuscaloosa and Lafayette times, erosion was stimulated either by gentle uplift or heavier precipitation, and transportation of the coarse residuum to the embayment followed.

The source of the Tuscaloosa was doubtless the residual chert developed on the adjoining limestone uplands. Silicified Mississippian fossils are relatively common, suggesting that the Mississippian cherts constitute the bulk of the gravel. The presence of Silurian fossils suggests, however, that the older cherty formations also contributed sediments.

The Lafayette gravel seems also to have been derived principally from the cherty formations adjoining the embayment, including not only the various cherty limestone formations, but also the Devonian formations of southern Illinois, which are almost entirely chert and have an average total thickness of 1,250 feet. Much of the Devonian chert is now

highly fractured and if similar conditions were present during Lafayette time, the formations could readily have furnished large quantities of chert gravel.

The quartzites of the Lafayette demand special consideration. The purple and pink varieties are foreign to the states of Illinois, Kentucky, and Missouri; therefore, they evidently came from outside the states. In Kentucky some brown and gray quartzites have doubtless been derived from quartzitized sandstone formed along faults.

The exact source of the quartz pebbles found in the Lafayette is not known. Some of them may be foreign to the region adjoining the embayment, but it is thought that many of them may have come from the conglomeratic phases of the Pottsville formation which partly bounds the embayment.

The fact that the gravel of the Lafayette is practically all well rounded is sometimes cited to show that it has been subject to long attrition and possibly transportation for long distances by streams. Although this may be true for many of the Lafayette pebbles, it is thought that many of the pebbles in the upper part of the embayment area may have had the following history.

The Lafayette chert pebbles representing a residuum of limestones or the weathered product of the Devonian chert formations or similar formations probably underwent a long period of weathering during which they lay in a clay or fine chert matrix subject principally to the solvent action of ground water. Under such conditions the outer surface of the chert fragments weather to the soft pulverulent material commonly called tripoli or soft silica, and the interior core of unweathered chert ordinarily has a smooth rounded contour; therefore, whenever the original fragments became subject to stream erosion they lost their soft, outer, weathered coat and after being transported a short distance became well rounded pebbles. Definite evidence of this phenomenon may be seen in the Devonian chert formations of Illinois to-day as well as in the cherty residuum of many limestone formations.

It is thought that the Lafayette gravel, subsequent to deposition, was elevated and subjected to a long period of weathering under semi-arid conditions and periodic rainfall and that the brown stain which penetrates most of the pebbles 1/8 or 1/4 inch was developed at that time. The gray chert found locally in Illinois may represent deposits of Lafayette which for some reason were not exposed to weathering and may be unaltered Lafayette gravel.

The sands of the Lafayette seem to have been derived from the surrounding land masses and previous embayment sediments. The average content of heavy minerals in three samples of Lafayette sand is 0.36 per cent,—less than in the Lagrange and Ripley formations, although the minerals are present relatively in the same amount as in the Lagrange.[1] The total amount of kyanite and staurolite present is in excess of that in either of the two older sandy formations. It is possible that the quickened action of the streams, resulting in greater carrying power, added to the Lafayette an additional quota of these metamorphic minerals.

COLLUVIUM

The colluvium of the upper part of the embayment seems to represent a small amount of wash from the adjoining hills during the post-Lafayette weathering period, added to the residual material developed from the leaching of the Lafayette. Locally the Ripley formation, where not covered by Lafayette, has a thin coating of similarly derived material.

DISCUSSION

GAIL F. MOULTON, Meridian, Mississippi: I note what seem to me to be three important facts regarding the sediments described in the paper by Lamar and Sutton: (1) calcareous material is absent, probably due to leaching; (2) some of the cherts containing Silurian and Devonian fossils indicate local origin for some of the sediments; (3) some of the material, such as the pink quartz, is entirely foreign to the area. The last fact and its relation to the sediments of local origin seem to me to be sufficiently important for additional comment.

J. E. LAMAR: Mr. Moulton has pointed out three of the outstanding features of the Cretaceous and Tertiary sediments of the area discussed. The quartzites offer an exceptional problem, and further detailed knowledge of the Lafayette in its outlying phases is necessary to make a complete understanding and interpretation of the phenomenon possible.

A further point which might be emphasized is the fact that it is suggested that much of the Lafayette gravel may have been derived locally from deposits of chert composed of pebbles already in a sub-rounded condition, so that transportation for only a short distance produced the rounding typical of the Lafayette pebbles in the upper part of the embayment.

[1] C. E. Dutton, *op. cit.*

BUILDING OF MISSISSIPPI DELTA[1]

ARTHUR C. TROWBRIDGE[2]
Iowa City, Iowa

ABSTRACT

The delta of Mississippi River seems not to extend much, if any, above Baton Rouge and not to be as old as the Pliocene Citronelle formation. Its coarsest sediments are fine sands with very fine sand, coarse and fine silt, and clay admixtures. Its finest sediments are clays or ultra-clays. With the exception of Old River, through which Mississippi River waters commonly discharge into Atchafalaya River, all the natural distributaries are closed artificially by levees down as far as the Forts. Below the lower ends of the maintained levees there are three distributaries: Batiste Colet's Bayou, the Jump, and Cubit's Gap. At Head of Passes the river breaks up finally to form Pass a Loutre, South Pass, and Southwest Pass. An explanation of the method and rate of delta building is attempted.

This paper is based on part of a season of field work at and below New Orleans with the United States Geological Survey in 1921, a season of field and laboratory work in the same area in 1922 with the United States Engineering Department, and a large amount of analytical work on collected samples in the sedimentation laboratory of the University of Iowa since 1921. Some of the data here given are based upon field work by Max Littlefield from the mouth of White River to New Orleans in 1926 and on field work by Victor H. Jones on Red River in 1928. Both Littlefield and Jones served as research assistants to the writer. Most of the analytical work was done by Max Littlefield. The United States Coast and Geodetic Survey collected nearly six hundred gulf-bottom samples off Southwest Pass in 1921, which were studied especially from the standpoint of final disposal of sediments carried to the gulf by this largest distributary of the river. All of the work was of a preliminary nature, but some of the results are now presented for what they may be worth.

Considerable parts of the paper are taken from an unpublished report entitled "Preliminary Geological Report on the Mississippi Delta," prepared after the field season of 1922 and submitted to the

[1]Read in abbreviated form before the Association at the New Orleans meeting, March 20, 1930. Manuscript received by the editor, March 18, 1930.

[2]Professor of geology, State University of Iowa.

United States District Engineer in New Orleans early in 1923. In rewriting parts of this earlier paper the writer had the benefit of careful criticism by M. I. Goldman and F. E. Matthes.

DEFINITION OF THE DELTA

In the opinion of the writer the noun "delta" and the adjective "deltaic" should be applied only to those sediments that are deposited by rivers under conditions that exist at and near their mouths. The delta includes neither the sediment deposited between erosional valley walls on the flood plain upstream from the delta nor the material turned over by the stream to ocean waves and currents and distributed on the sea bottom beyond the places where the current of the river leaves it. On the delta the river loses volume by distribution unless artificially prevented from so doing, whereas on the flood plain the volume is increased by tributaries that enter the main stream where it touches the walls of its valley in spite of natural levees, and any distributaries that form are turned back by the bounding valley walls to re-enter the stream, causing it to anastomose. Streams that enter the main valley on the flood plain near the head of the delta may follow independent courses to the sea if the river does not touch its valley walls below the points where the secondary streams enter the valley. Too commonly neritic, surf, or littoral sediments that may or may not have been brought to the sea by streams but were deposited *by the sea* and not *in the sea by streams*, are said to be deltaic.

If deltas are as thus defined, the delta of the Mississippi does not extend to the mouth of the Ohio and include all of the Tertiary formations of the Mississippi embayment, as is so commonly stated in textbooks, and it does not extend into the gulf many miles beyond the present shore line. Study of the Tertiary formations indicates that they are no more largely deltaic in the Mississippi embayment than they are in their extensions along the strike eastward to Florida and westward and southwestward to the Rio Grande. The whole of the immediate valley of Mississippi River in the Driftless Area of Wisconsin, Illinois, Minnesota, and Iowa, appears to have been cut since the close of the Tertiary and there is no evidence that the river existed in Tertiary time.[1]

The Pliocene Citronelle formation,[2] the outcrop of which is crossed by the river above Baton Rouge, is not a part of the delta and was eroded

[1]A. C. Trowbridge, "The Erosional History of the Driftless Area," *University of Iowa Studies in Natural History*, Vol. 9, No. 3 (1921), pp. 55-127.

[2]G. C. Matson, "The Pliocene Citronelle Formation of the Gulf Coastal Plain," *U. S. Geol. Survey Prof. Paper 98* (1916), pp. 167-92.

by the river so that it forms the erosional walls of the valley there. The delta sediments and the flood plain sediments upstream from the delta lie unconformably on the Citronelle. Ohio, White, and Arkansas rivers are tributary to the Mississippi on its flood plain. The valley walls bordering the flood plain extend on the east side of the river almost to Baton Rouge and on the west side below the mouth of Red River, and the head of the delta might be located at or near Baton Rouge, but because under the most common conditions Mississippi River discharges westward through Old River to join the waters of Red River and flow to the gulf through Atchafalaya River, the vicinity of Three Rivers is generally considered to be the upper end of the delta (Fig. 1).

For the locations of places on the delta, to be mentioned in this paper, see Figure 2.

PROBLEMS OF THE DELTA

As was brought out by Hilgard,[1] the Mississippi delta is not typical of the deltas of the world. Instead of being spread out more or less in the shape of the Greek letter *delta*, it consists of a long, narrow belt of land that breaks up in the outer part into long branching finger-like extensions, some of which, as parts of the delta, have approximately the shapes of whole deltas elsewhere. In general outline, the Mississippi delta resembles a human hand more nearly than it does the Greek letter *delta*. The long narrow part that extends about 90 miles below New Orleans represents the forearm and wrist, the area where the main distributaries branch off, beginning at the Jump and Batiste Colet's Bayou and extending to and including Head of Passes, is the palm of the hand, and the passes themselves and the digitate lands built by them are the fingers.

Among the many problems pertaining to the delta and its manner of building, studies made or directed by the writer should contribute something to the description and explanation of the situation at Three Rivers at or above the approximate head of the delta; the long, almost unbranched, crooked course of the river from Three Rivers to New Orleans; the now unbranched course of the river from New Orleans to the lower ends of the artificial levees, where the river is notably straight but has a few anomalous bends; the great eastward-projecting land of St. Bernard Parish almost enclosing lakes Borgne and Ponchartrain, and Chandeleur Island still farther east; the branching outlets below

[1] E. W. Hilgard, "Exceptional Nature and Genesis of the Mississippi Delta" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 17 (1907), p. 731.

FIG. 1.—Map published by U. S. Geological Survey showing areas below Cairo subject to flood by the river.

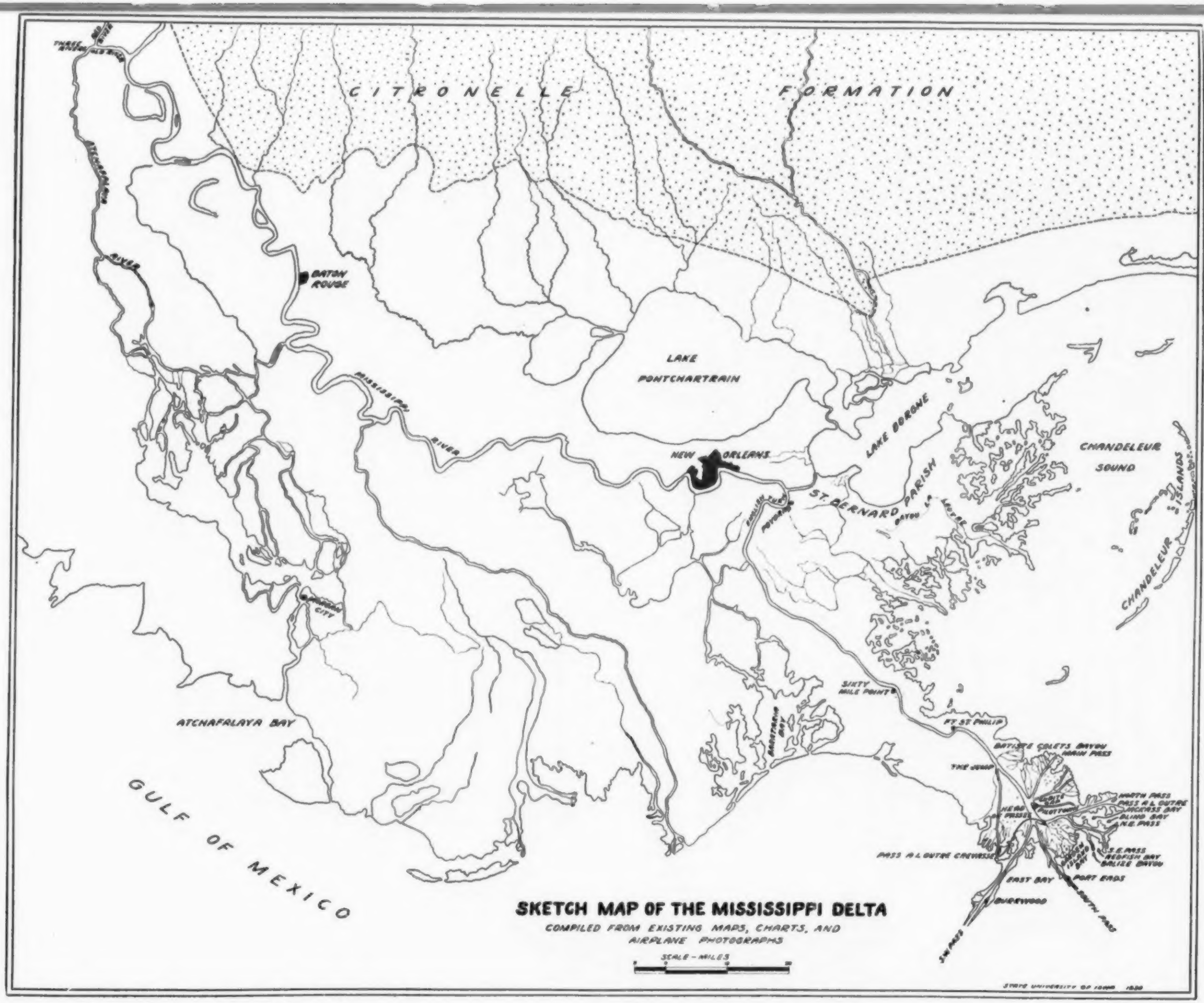


FIG. 2.—Sketch map of Mississippi delta, compiled from existing maps and charts and from airplane photographs taken for the U. S. Coast and Geodetic Survey by the Navy.

the ends of the artificial levees that lead off toward the east from the main river, including Batiste Colet's Bayou, Cubit's Gap, and Pass a Loutre; the westward distributaries on the lower delta, most of which are long, straight, and almost unbranched, including the Jump, Southwest Pass, and South Pass; the situation at Head of Passes; the mud-bottomed bays in the angles between the branching pass lands at the outer edge of the delta, including Jackass, Blind, Redfish, Garden Island, East, and West bays; the mud lumps that appear from time to time on the south and west sides of the outer ends of the main passes; the coarseness of the sediments deposited in bars near the head of the delta, on natural levees, in passes, on the bars outside the mouths of the passes, and in the bays; the making and closing of branching mouths; the up-river slope of the bottoms of the passes; and the final disposal of sediments in the gulf beyond the pass mouths. It could not be expected that the solution of all these problems could be attained as a result of the brief studies that have been made, or that they could be brought within the scope of so brief and so preliminary a paper as this. Some facts and principles are here stated, however, in the hope that at least they may constitute starting places for other workers.

THREE RIVERS

Conditions are such at the mouth of Red River that normally water from the Mississippi flows out through Old River and joins water from Red River to flow to the gulf through Atchafalaya River, thus constituting a distributary of the Mississippi. Under exceptional conditions, when the Mississippi is low and Red River is high, the slope in Old River is reversed and some of the water of Red River is tributary to the Mississippi River, the remainder going down the Atchafalaya to the gulf.

Thus at some times Red River contributes sediment to the main Mississippi delta and at others Mississippi River contributes sediment to the subsidiary delta of the Red and Atchafalaya. The sediments now handled by Red, Atchafalaya, and Old rivers are shown in Figure 3.

Red River probably flowed originally from its erosional valley and was a normal tributary of the Mississippi. The building of the natural levee on the west side of the main river forced Red River to take a parallel course and to flow independently to the sea. There is no place below Three Rivers where the Mississippi touches its west valley wall so as to let the Red or the Atchafalaya back again.

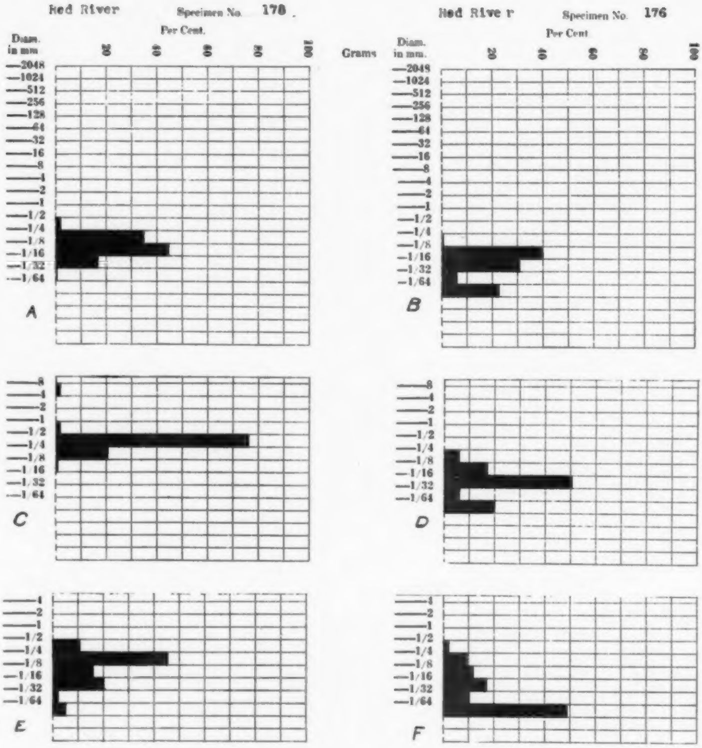


FIG. 3.—Mechanical analyses of sediments from Three Rivers: *A*, coarsest sample from bottom of Red River; *B*, finest sample from bottom of Red River; *C*, coarsest sample from bottom of Old River; *D*, finest sample from bottom of Old River; *E*, coarsest sample from bottom of Atchafalaya River; *F*, finest sample from bottom of Atchafalaya River.

FROM THREE RIVERS TO NEW ORLEANS

A glance at the map of the lower Mississippi (Fig. 2) shows that the river is much more crooked above than below New Orleans. The curves above Baton Rouge are probably ordinary meanders on the flood plain. Those between Baton Rouge and New Orleans have not been studied carefully and their nature and origin are not known.

Littlefield, who made a special study of the bars below the mouth of Arkansas River[1] and found that between 400 and 700 miles below Cairo there was a gravel bar consisting of pebbles as large as 64 millimeters in diameter just downstream from almost every bend, concluded that most of these gravels were locally derived from a valley fill probably of Pleistocene age. He is quoted as follows.

Below the mouth of Red River the quantity and size of the pebbles decrease, except where the river crosses the Citronelle formation, and no gravel was found in the lower 150 miles of the river.

THE DELTA AT NEW ORLEANS

The city of New Orleans is built on the natural levee of Mississippi River. As shown in Figure 2, it occupies the area within a bend of the river nearly 5 miles across and 3 miles deep, and spreads beyond the bend toward the east and to Lake Ponchartrain on the north. According to a map of the Sewerage and Water Board of August 7, 1919, the natural elevations along the river bank range from 6 to 16 feet above mean gulf-level and the surface slopes back from these levels to a basin 1 foot or less below gulf level north of Claiborne Avenue. There is another such basin in the neighborhood of Earigny and Elysian Fields avenues. North of these basins there is a ridge whose crest is 3-5 feet above gulf-level, that was probably built by Bayou Sauvage and later cut through by Bayou St. John. North of the ridge the land is less than a foot above sea-level and slopes imperceptibly to Lake Ponchartrain. The city is of course protected by an adequate levee system.

The sediments at New Orleans, as shown by drillers' logs of borings at the Industrial Canal and laboratory analysis of the samples taken from these borings, are sands, silts, and clays. Mechanical analyses of the finest and coarsest samples are shown in Figure 4.

These seem to be normal sediments of the natural levee. They do not represent the coarsest load that is carried along the bottom of the river, but the suspended sediments that were deposited from the surface waters as the river overflowed its banks in time of flood. They may, however, have been deposited in the gulf out in front of the crest of an offshore bar when the mouths of the river were still north of New Orleans. In these sediments are many undecayed cypress stumps, some of which are at least as low as 12 feet below sea-level. The trees grew in the swamps much as they do to-day, and later the sediments settled,

[1]Max Littlefield, "Mississippi Gravels Below the Mouth of Arkansas River" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 38 (1927), p. 147.

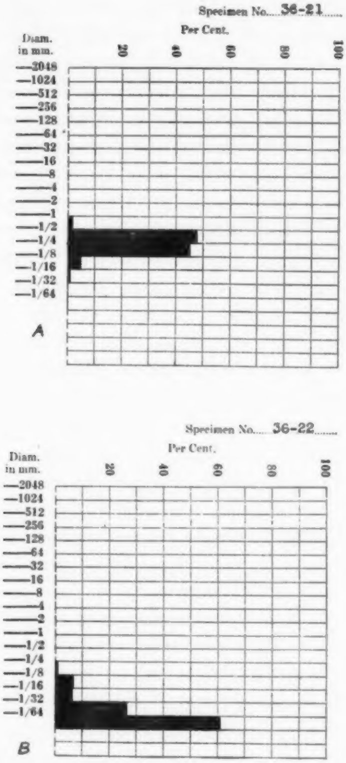


FIG. 4.—Mechanical analyses of coarsest and finest samples taken from boring No. 2 at the Industrial Canal at New Orleans: *A*, collection 36-21 from 61 feet below gulf level; *B*, collection 36-22 from 65 feet below gulf level.

carrying the stumps down with them. The total amount and rate of settling have not been determined. The settling is probably due to the compacting of the underlying sediment rather than to diastrophic subsidence of the delta as a whole or to surficial drainage or decay of vegetable matter.

At depths greater than 43 feet below sea-level, recent marine shells are found in sand that probably represents the subaqueous part of the delta buried under the subaerial part as the delta was built out into the gulf.

There has been much speculation as to the thickness of the delta material at New Orleans. Humphreys and Abbot[1] contended that there was a formation of clay of early Eocene or possibly Cretaceous age, dipping with the river and lying with its surface near low-water level throughout the delta. They give a log of a 630-foot well at New Orleans and state that no material penetrated, lying more than 57 feet below gulf-level, was deposited by the river. Hilgard had nearly the same idea. It is agreed that the strictly land deposits of the delta at New Orleans where marine shells begin, are limited to a few feet at the surface, but below this lie the materials which were being deposited on bars at the mouth or mouths of the river at the same time that land deposits were being laid down farther north. This material also is part of the delta and of essentially the same age as the alluvium which overlies it. The change from marine sand, silt, and clay containing marine shells, upward to sand, silt, and clay without such shells merely records the slow migration of the natural levees, bays, and marshes out over the bars, as the delta grew gulfward. It is believed that all the samples collected from the Industrial Canal borings belong with the delta and that they constitute a conformable series, differing in age only as each layer is slightly younger than the underlying one.

BAYOU LA LOUTRE LAND

The map (Fig. 2) indicates that Bayou la Loutre is the remnant of what was formerly an important pass heading about where Poydras now is, breaking up into many mouths and discharging into the gulf at or perhaps beyond Chandeleur Islands. The land extends far out toward the east and spreads northward east of Lake Borgne. The bayou land is too wide and too high to have been built by anything but a large pass of long life. So far as known, Chandeleur Islands consist of sand, and it is thought that they may be the result of wave action on old pass bars. In Chandeleur Sound, between the islands and the shore, there are many small islands. Most of these seem to be normal sand or shell beaches, but one small island near the north end of the Free Mason group has a mud foundation. The upper part is shells, chiefly of oysters, but about 6 inches of dark-colored mud is exposed at low tide at the base. Although there is no living vegetation, the mud contains many stumps, each about 1 inch in diameter, where the waves have cut in. Although neither the mud nor the stumps have been thoroughly analyzed, the mud has the appearance of having been deposited in a swamp or on a natural levee

[1] *Corps of Engineers Prof. Paper 4*, p. 93.

of the delta, and the stumps appear to be mangrove similar to that which grows to-day in the bays and on the beaches and bayou lands in the outer parts of the delta.

Until about the time of the Civil war, St. Bernard Parish, located on the eastward projection of the old delta, was occupied by an aristocratic and prosperous people who had fine houses and permanent roads and buildings and raised large crops of fine long staple cotton. The pass probably silted up at its mouths as all the passes that discharge toward the east seem to do, probably because of the prevailing east winds that keep these passes partly ponded. Finally, the building of the artificial levee across the head of the distributary prevented further deposition of sediment on this land except when crevasses occurred, as in 1922, and by dynamite in 1927, and by the compaction and settling of the sediment and by the erosive work of the waves of the gulf, this land has slowly settled until now it is fit for nothing but fishing, hunting, and trapping by a poverty-stricken population. This seems to be the ultimate fate of all parts of the delta not renewed by periodic overflow.

BENDS BELOW NEW ORLEANS

There are only four conspicuous bends on the lower delta: one at New Orleans, one at English Turn 15 miles below New Orleans, one near Sixty Mile Point 60 miles below New Orleans, and one near Fort St. Philip about 75 miles below New Orleans and 20 miles above Head of Passes. The tendency seems to be for the river to produce long straight passes at the lower end of the delta, and the development of sharp bends is anomalous. The bends at and below New Orleans are certainly different in character from those above Baton Rouge, which migrate according to the custom of ordinary flood-plain meanders.

It seems most likely that the bends at and below New Orleans have resulted from the forming and closing of bayous or passes. If a branching mouth that turns sharply to right or left as the mouths of the river were pushed out into the gulf by delta building became the main channel of the river, and outlets that went straight on or turned in the opposite direction were silted up and closed, such bends would result. For example, the river would have some such bend as at English Turn, at the head of Pass a Loutre, should South and Southwest Passes be closed, or at the head of Cubit's Gap if Main Pass were the main outlet to the gulf (Fig. 2).

CREVASSING

The formation and breaking of natural levees, which are important factors in delta building, are somewhat analogous to the building and crevassing of artificial levees.

In the many places where the New Orleans levee is below the established grade, there would have been overflow from the river at the crest of the flood in 1922, had it not been for temporary measures taken to prevent such overflow. If the Poydras Crevasse had not been formed and the additional rise anticipated after April 27 had been realized, the levees would have been overtopped even where they were up to standard grade. In 1927 the artificial levee was dynamited just below Poydras in order to prevent the overflowing of the levees at New Orleans. Due perhaps to these facts, there has been much recent increase in the agitation in favor of spillways. It was proposed that the Poydras Crevasse be left open so as to reduce the danger of overflow at New Orleans. The building of one or more new spillways below New Orleans has also been advocated, to lead large volumes of water off into Lake Borgne in flood time. Spillways are a part of the current plan for flood control.

Those who advocate spillways as a measure of flood control are opposed by those who propose to raise all levees to grade, to raise the grade as required by possible future increase in flood stages, and thus to permit flooding only over the outer delta below the ends of the artificial levees where the land is of relatively little value and where little damage is done by overflowing.

The writer has little to offer on this subject and that little falls on both sides of the question.

The main danger at New Orleans in time of flood is not from overflow, but from caving, the channel being very deep and narrow compared with that, for example, at Memphis. There is always plenty of time to raise levees temporarily after a high flood is known to be coming and before its arrival. Except as the submerged banks are protected, there is as much danger of caving at New Orleans as at Poydras. It is not clear that a spillway below New Orleans would lessen this danger materially. Indeed, it seems, rather, that the lowering of the flood surface below New Orleans would tend to increase slope and velocity at New Orleans, so as to increase rather than decrease the danger of caving there.

However, such artificial openings are desirable, because of the sediments the overflow water deposits. Breaks have occurred naturally from time to time, with beneficial results. Cubit's Gap, which was

artificially opened in 1862, has built a large amount of land which is now used for hunting, trapping, and fishing. The same is true of the Jump and Batiste Colet's Bayou. When in 1891 the Pass a Loutre Crevasse began rapidly to enlarge, there was such great alarm concerning the harm it would do to South Pass that large sums of money were spent during a period of years in attempts to close it. But, with the exception of 6½ hours in 1898, it has remained open. Not only was no permanent harm done to South Pass, but about 20,000 acres of land were built in Garden Island Bay, which now serves as a public hunting preserve.

If there had never been breaks in the river banks, the delta would have consisted merely of a narrow and precarious strip of land on either side of the river extending far out into the gulf. With the formation of lateral outlets in the past, came a spreading of the deposits and the addition of a correspondingly large area. With the building, raising, and maintenance of the levees, the upbuilding of these delta lands ceased except as crevasses have occurred from time to time and from place to place. Settling, however, and erosion due to wave action have continued and will continue, slowly but surely lowering these lands and eventually causing their submergence again beneath the waters of the gulf. Spillways, if properly located and especially if re-located from time to time, would offset these destructive processes, in a small way at least, and would delay, at least in some places, the submergence of these lands.

It seems clear, from a study of the Poydras and Myrtle Grove crevasses of 1922, that spillways could be made to raise the level of land already high enough for agriculture, but there is no evidence in the results of these crevasses that any considerable amount of land would be reclaimed from the sea in this way. There would probably be more new land formed if the whole river were allowed to continue to spread naturally below the ends of the levees.

EASTWARD DISTRIBUTARIES

BATISTE COLET'S BAYOU

Batiste Colet's Bayou, the first distributary of the river below New Orleans, is of a branching type that seems to characterize the mouths on the east side of the river, including the old Bayou la Loutre described above and Cubit's Gap and Pass a Loutre farther down the river. At its head a single channel 200 feet wide, it branches within less than a mile and each branch breaks up into other branches which in turn divide so that at the gulf it has a dozen mouths or more.

The manner and rate of gulfward growth of these outlets are interesting. At the outer end of one of the typical passes there is a flat about 100 feet wide extending out 1,000 feet or more beyond the ends of the banks made permanent by vegetation. The highest parts are only an inch or two inches above low tide. The material is hard, ripple-marked sand. The exposed flat is not continuous, but the water in the breaks is only a few inches deep. This new deposit is separated from the ends of the pass by a shallow channel cutting across it toward the north. This may persist and form a branching bayou when the pass banks have been established beyond this point. The distance between these new and really not yet established banks is somewhat more than the width of the pass above. Conditions are similar at the northernmost mouth of Batiste Colet's Bayou, which divides into three channels with new flats bordering each, and a branching bayou pattern is already marked out. Each channel branches and branches again. It is readily seen that the permanent establishment of these flats as banks and of some of the channels as branching bayous will simply extend the bayou gulfward as it is above. The airplane photograph of Figure 5 makes it clear that the branching of this and other similar bayous is probably accomplished in this way before the banks have been built to sea-level.

It is probable that this incipient branching accompanying growth is due, at least as a contributory cause, to the prevailing easterly winds which tend to pile up the gulf water here, thus reducing the slope in the bayous, and to check the currents in the bayou through surface friction, thus causing deposition of sediments which choke the mouths and cause branching.

The rate of growth can not be determined accurately. The 1874 chart of the Coast and Geodetic Survey shows no land built out beyond the normal river bank, which is mapped as about 1/5 mile wide. A rough map made up from airplane pictures taken in 1922 shows a length of more than 4 miles. Outside one of the mouths, that part of the flat which is uncovered at low tide only, extends more than 3,000 feet beyond the grassy ends of the pass. In 1922, flats occurred in one place where in 1920 the launch El Bonito drawing 2½ feet of water was run with plenty of water. The mouths seem to have lengthened at a rate of about 500 feet per year on the average.

CUBIT'S GAP

Cubit's Gap is reported to have been opened by two young women, daughters of a man named Cubit, in 1862. A canal which was first made

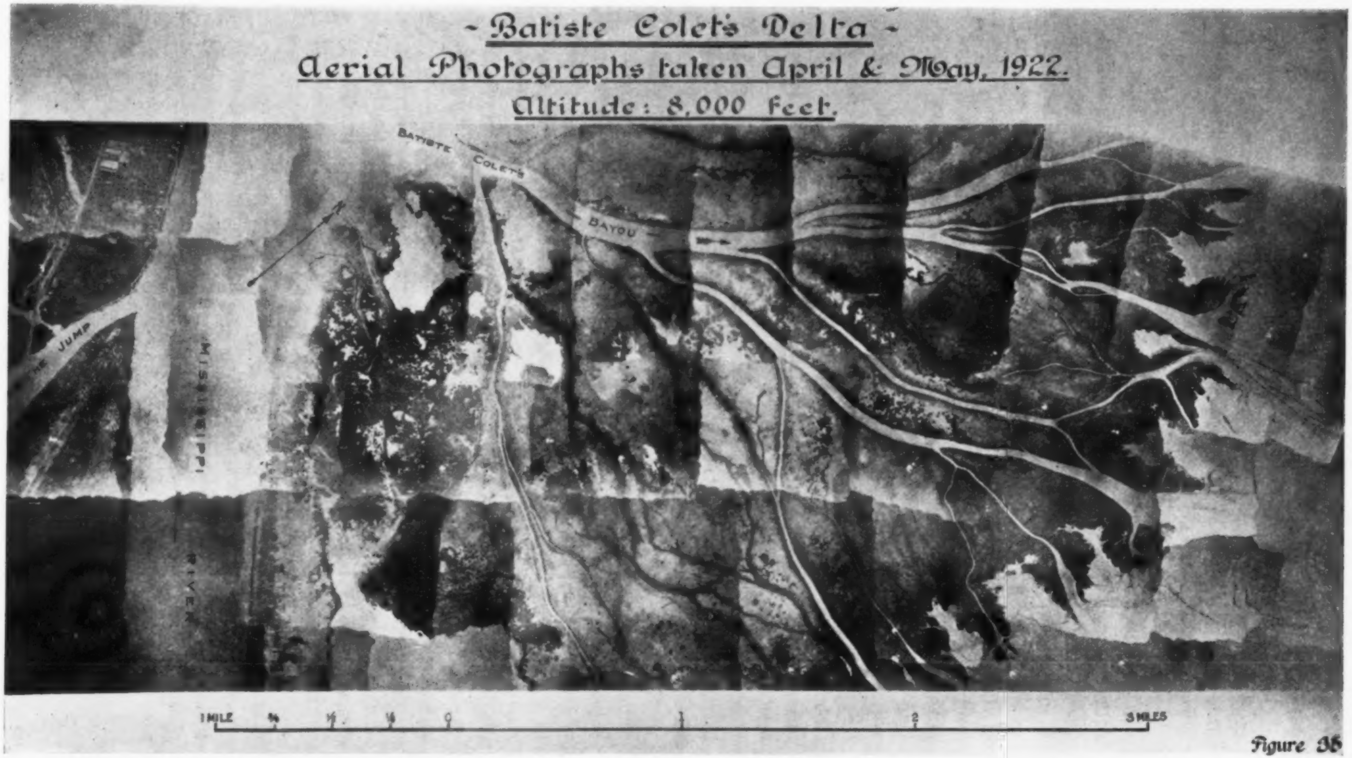


FIG. 5.—Airplane photograph mosaic of outer part of Batiste Colet's Bayou, showing new flats separating branching channels.

by spading was enlarged and deepened by flood discharge from the river until a permanent distributary was formed. One of the women who did the digging still lives at Pilottown.

Within the 60 years of the history of the gap, between 1862 and 1922, the outlet grew to a maximum length of 8 miles, and about 70 square miles were added to the delta land, indicating a longitudinal growth of the gap of about 700 feet per year and the addition of more than 1 square mile of land per year. Cubit's Gap land has been so widely spread as now to extend from close up to the southern mouths of Batiste Colet's Bayou on the north to continuity with Pass a Loutre land on the south. The crowding of the sub-delta has turned back some of the distributaries, causing them to join others again and giving Cubit's Gap a braided appearance.

Cubit's Gap breaks up into three main passes within about 2,000 feet of its head. In this respect it bears a strong resemblance to Batiste Colet's Bayou. It seems likely that this first division took place at or near the gulf border as it was before the gap was opened. If so, it was doubtless due to the choking of the mouth by the deposition of bars. The greatest deposition, hence the shallowest water, would be in the direct line of the main current. Channels would avoid the resulting bar as the mouths were projected gulfward by the extension of their banks and bars.

Main Pass of Cubit's Gap is long, almost straight, and practically unbranched except near its outer end where there are a few distributary bayous. Its banks are parallel from its head nearly to its outer end where there is a slight divergence causing an incipient bell shape.

Main Pass is clearly being elongated at its mouth with considerable rapidity. Longitudinal flats, for the most part so recent in origin that they are still bare of vegetation, extend far out beyond the vegetation-covered ends of its banks. These flats are barely covered by water at high tide and are exposed in large areas at low tide.

As at Batiste Colet's Bayou, these new flats are broken by many shallow, branching channels. Especially is this true on the south side. The main mouth appears to be turning northeastward as it grows, causing the branching channels on the south side to lead out from the outside of a bend in lines more nearly in the projection of the upper straight course than is the main mouth.

One is forced to a choice between two conclusions: (1) that Main Pass is changing its habit from the maintenance of a single, unbranched channel during past growth to the development of many branching mouths at present, or (2) that there has always been this branching at

the mouth with most of the distributaries gradually closing as the banks of the main pass became permanent and its mouth grew straight out in the line of its elongation. The writer favors the second conclusion, for old outlets increase in number as the mouth of the pass is approached and those which are left are reported to be rapidly closing due to deposition of bars across their heads. Coast and Geodetic Survey Chart No. 194 shows that in 1904, when the survey was made, Main Pass had many distributaries of considerable size along its north bank. The recent airplane photographs show these same distributaries as small and unimportant or as having been entirely eliminated. This seems to be the normal method of extension, at least for distributaries toward the east, but here the incipient bifurcating passes atrophy and a single large pass results.

The bar at the mouth of Main Pass is fairly typical for so large a pass discharging into such shallow water. At the Coast and Geodetic Survey tower on the bank near the mouth, blue mud was taken from 7 feet of fresh water (Collection 124, Fig. 6, *A*).

Before the crest of the outer bar had reached this point in its eastward migration, the mud was deposited as mud is being deposited to-day beyond the bar crest (Collection 125, Fig. 6, *B*). The crest of the bar, consisting of sand, then advanced over the mud, since which time this mud has been uncovered again by re-excavation behind the advancing bar.

The water was only 3 feet deep on the crest of the bar on the day of observation. The bar on the crest consists of hard sand covered by an exceedingly thin layer of fine gray mud. Within 1,000 feet outside the crest of the bar, the water deepens to 6 feet and is salty at the bottom. Here the bottom materials consist of 3 feet of very fine flocculated mud (Collection 125, Fig. 6, *B*) overlying sand (Collection 126, Fig. 6, *C*). The sand is believed to represent the foreset beds of this sub-delta deposited during the 1922 flood, and the overlying mud was probably deposited during the following low-water stage when the water was exceptionally turbid and the current was not sufficiently strong to displace the salt water and to carry the fine material farther out. This is the greatest thickness of flocculated material discovered at any of the mouths of the river. Its accumulation here may be due to the fact that salt and fresh water mingle at shallow depths and that this location is protected from strong waves and currents which carry off the fine material in places of greater exposure.

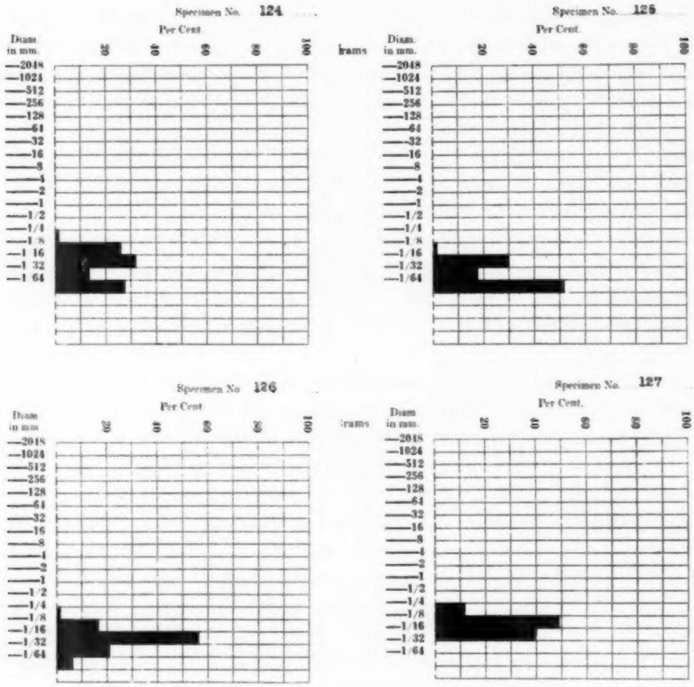


FIG. 6.—Analyses of samples collected from outer part of Cubit's Gap: *A*, sample 124, from 7 feet of water at C. and G. station in Main Pass; *B*, sample 125, from mud in 6 feet of water 1,000 feet outside crest of bar at end of Main Pass; *C*, sample 126, from sand underlying mud of sample 125; *D*, sample 127, from surface of sand flat on north side of outer end of Main Pass.

From the few experiments which have been made and from observation elsewhere, it is believed that this mud will be blanketed by sand as the bar continues to advance and become a part of the deposit.

The lateral flats are sandy at the surface (Collection 127, Fig. 6, *D*), but there are a few thin layers of mud in the sand, and the sand is only 3 feet thick, overlying soft mud of unknown depth. The lower mud was deposited in the shallow gulf before Cubit's Gap was formed and offshore from the mouths of the gap more recently. Then the lateral edges of the bar advanced over it. At present the surficial sand is in process of deposition, as a natural levee, when the pass overflows its incipient

banks in high-water stages. The sand gives place to mud within a few score feet in directions transverse to the pass. Aside from Main Pass there are many other passes and bayous of Cubit's Gap, all of which are of the branching type.

PASS A LOUTRE

As is shown in Figure 2, Pass a Loutre is of the branching type of outlet, due probably to the fact that it discharges into the teeth of the prevailing strong wind. At its head it is about 3,600 feet wide. Until 1891 its main branches were North Pass and Southeast Pass, which in turn gave rise to Northeast Pass and Balize Bayou, but more recently Pass a Loutre Crevasse has been added. At its head, North Pass is 40 feet deep, but it shoals to 22 feet at the end of its cane-covered banks, and to about 9 feet where it crosses the crest of its offshore bar.

According to the Coast and Geodetic Chart No. 194, based on a survey of 1867, Southeast Pass was then larger than Pass a Loutre, but now it is decadent and not half so large as Pass a Loutre. The bar off Southeast Pass consists chiefly of fine and very fine sand (Fig. 7). Balize Bayou, which was for years prior to 1822 a large navigable pass and had a town of several hundred people at its head up to the time of the Civil War, is now closed from head to mouth except for a few strips of peaty water about 10 feet wide.

Since 1891, when Pass a Loutre Crevasse became important, Garden Island Bay has been almost filled with sediment deposited by the branching outlets from this crevasse. The present branching mouths are shown in Figure 8.

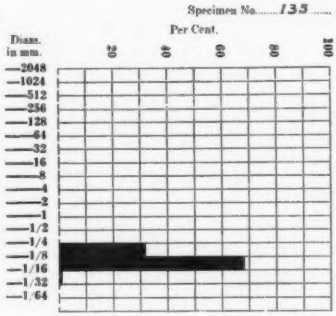


FIG. 7.—Mechanical analysis of sample 135 taken from 2 feet of water on crest of bar outside of Southeast Pass.

FIG. 8.—Airplane photograph of branching mouths of Pass a Loutre Crevasse.

WESTWARD AND SOUTHWARD DISTRIBUTARIES

Just as Batiste Colet's Bayou, Cubit's Gap, and Pass a Loutre are typical of the eastward distributaries of the river, the Jump and South and Southwest passes are typical of those that discharge toward the south and southwest.

THE JUMP

Although the Jump breaks up within a mile or two miles of its head into several passes, these passes from here to West Bay are long, straight, and almost unbranched. In the growth of this outlet from the first break in the river bank to the present condition, there seems to have been a general branching early, but the tendency to divide seems then to have ceased.

It is understood that the Jump was formed in 1839 by a natural breaking of the banks. The first break was into West Bay, far up from the open gulf, and there the new mouth was protected from gulf waves and currents. As the prevailing winds on the lower delta are easterly, the Jump was not and is not subject to strong onshore winds. These facts may explain the lack of minor branches in the outer part of the Jump. Perhaps the outlet first divided, as did Batiste Colet's Bayou, Cubit's Gap, and Pass a Loutre Crevasse, about where the outflowing water formed its first heavy deposit in the bay. There was a swift current of high volume, the velocity of which was checked at the bay. The heavy deposit resulting caused a choking of the mouth and distribution. Following the establishment of these several passes, however, each one, not having strong head winds to contend with, caused its bar and bank ends to migrate out into the gulf, as in South and Southwest passes.

Whatever the cause, the Jump has neither the branching character of the eastward distributaries, nor the dendritic arrangement of flats at its mouths. In fact, there are no projecting flats on the bay border of the land made by the Jump.

SOUTH PASS

Because South Pass has been since the days of Eads the main commercial entrance to the river and the port of New Orleans, it has been the subject of special study by the engineers who have been responsible for maintaining navigation, but so far as the building of the delta is concerned, it has no greater significance than the other large passes. The natural development of South Pass has been so interfered with by artificial improvement that it is difficult to determine what its natural tendencies are.

The waters of South Pass flow on the average in a direction S. 33° E. The course is almost straight. Due doubtless to artificial causes, the width, depth, and discharge have varied considerably within the last century. In 1922 it had an average width of 728 feet and an average depth of 33.9 feet and carried to the gulf about 15 per cent of the total discharge of the river below Cubit's Gap.

Although supported on the east side by the land built by Pass a Loutre Crevasse, and partly on the west side by a long tongue of land built by Grand Bayou before this bayou was closed in the improvement of South Pass, the bank lands separating the pass from the bays on either side are very narrow. At the narrowest place the width of the land is only 25 feet and at the widest place it is less than a mile. The land is highest at the pass banks and slopes gently to sea-level at the bays. Due to the widening of the pass the bank lands are getting even narrower. At the outer end of the pass, sand spits and reefs have been built of river-borne sand by surf waves and currents.

Outside the ends of the jetties the water shoals gradually until at a distance of 3,500 feet its average depth outside the commercial channel is 10-11 feet. This is the crest of the bar. Beyond this line, the water deepens to 100 feet within about 2 miles of the ends of the jetties.

The crest of the bar is not a line, but a belt of considerable width where the water is shallow. The belt is curved into almost a half circle concave upstream with its ends connected with the jetties. On the average, the water is shallower on the outer curve of the bar, where the main current is, than on the sides near the jetty ends. This is to be expected, for the largest deposit is made where the swiftest current and the bulk of the sediment reach the gulf, and this is a little west of the projection of the middle of the pass. The surface of the bar is pockety and lumpy. This is probably due to the building out of miniature sub-bars on the surface of the main bar and to eddies over and around these bars.

One of the coarsest samples collected on the whole delta (Fig. 9) came from the crest of the South Pass bar in 11 feet of water. The finest sands, the silts, and the clays are notably scarce or lacking. Shaw[1] reports only sand on the outer slope of the bar as far out as the 50-fathom line and the presence of bottom mud in the gulf for long distances west of the mouths of Mississippi River. The inferences are that the whole load of the river is sluiced out to the crest of the bar, that the sand is

[1]E. W. Shaw, personal communication.

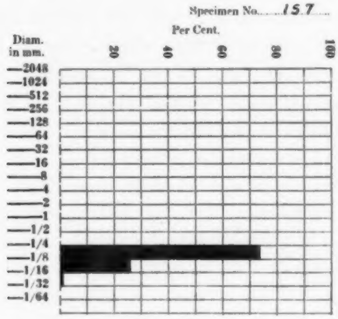


FIG. 9.—Mechanical analysis of sample 157 from 11 feet of water on crest of South Pass bar.

deposited on the crest and the outer slope of the bar, and that the silts and clays are in the main not added to the delta, but are distributed widely over the gulf bottom by the currents which here flow toward the west.

Estimates seem to show that the rate of advance of the crest of the South Pass bar into the gulf has decreased within the last century from about 100 feet per year to about 40 feet per year, as it is to-day. This decreasing rate is probably due to the facts that as the bar moves forward into deeper and deeper water there is a larger vertical distance to be filled between gulf bottom and sea-level, and that, as it grows outward, stronger and stronger gulf currents are encountered which prevent the immediate deposition of an increasingly large proportion of the river's load.

SOUTHWEST PASS

Southwest Pass is longer, wider, and deeper than South Pass. From head to mouth it is approximately 20 miles long. From near the head to a short distance above Burrwood, the average width is about 1,200 feet, the central depth about 70 feet, and the mean depth about 58 feet. Near the mouth the pass widens and the depth decreases.

The bank lands are wider than those of South Pass and in some places it is several miles from pass to bay. In some places the bank lands have become considerably narrower in recent years, due almost entirely to settling and the cutting of waves from the bays. The pass banks afford clear evidence neither of widening nor of narrowing of the pass. There are, however, a few places where new banks are forming, and about as many where banks are being cut back slightly.

Before the improvement of Southwest Pass, it had a number of unimportant subsidiary passes through which some water was distributed into the bays both east and west of the main pass, but all are now practically closed either naturally or artificially. As shown in Figure 2, these distributaries built finger-like lands, most of which have been considerably reduced in area since they were built.

The bar outside the mouth of Southwest Pass is similar in many respects to the South Pass bar. In September, 1922, the water was less than 15 feet deep in the shallowest place about 2,500 feet out from the ends of the jetties, and less than 1,000 feet farther out the depths increased to 50 feet. Only two collections were made by the writer on the surface of the bar, one in 25 feet of water near the crest (Fig. 10-*A*) and the other in 50 feet of water on the outside slope of the bar (Fig. 10-*B*). The sam-

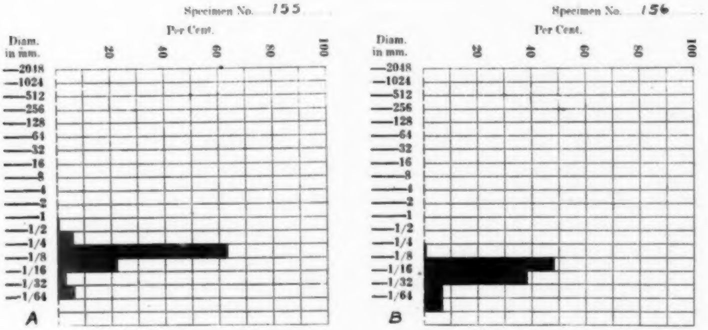


FIG. 10.—Mechanical analyses of samples from Southwest Pass bar: *A*, sample 155 from 25 feet of water on crest of bar; *B*, sample 156 from 50 feet of water on outer slope of bar.

ple from the crest is mainly fine sand like the sample from the South Pass bar, and the one from deeper water on the outside slope of the bar is very fine sand and coarse silt.

For the general distribution and nature of sediments deposited on the gulf bottom off Southwest Pass as determined from samples collected in 1921 by the Coast and Geodetic Survey, see Figures 11 and 12 and a previously published abstract.[1] The coarsest sediment, shown on the map (Fig. 12) by oblique lines (Fig. 11-*C*), which lies on the surface of a submarine dome that stands more than 100 feet above its surroundings,

[1] A. C. Trowbridge, "Disposal of Sediments Carried to the Gulf of Mexico by Southwest Pass, Mississippi River" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 38 (1927), p. 148.

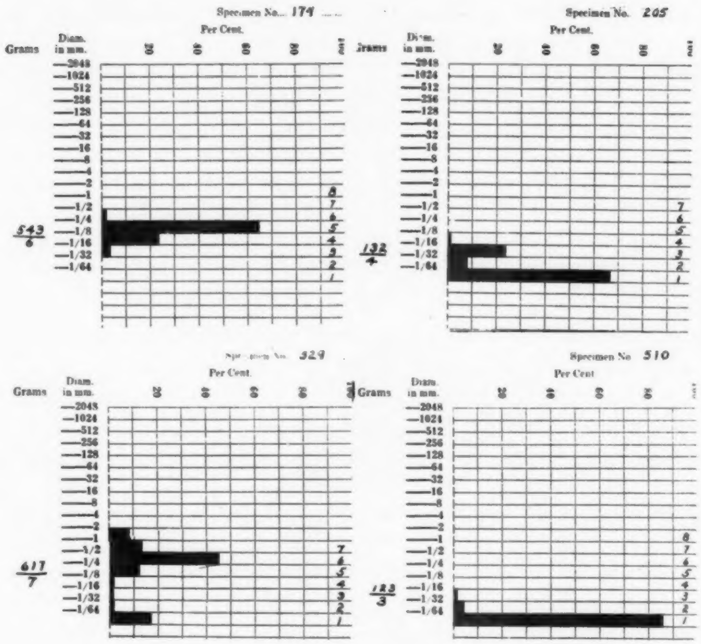


FIG. 11.—Mechanical analyses of typical samples of the four types of sediment shown in Figure 12. Different size grades are designated numerically on right of graphs. Numerators of fractions on left of graphs designate order of quantity of the three more plentiful size grades, and denominators designate coarsest grade in sample. *A*, sample 174 taken from crest of Southwest Pass bar in 4 fathoms of water; *B*, sample 205 taken from 3 miles beyond ends of Southwest Pass jetties in 12½ fathoms of water; *C*, sample 329 taken from surface of dome 19 miles beyond ends of Southwest Pass jetties in 52 fathoms of water; *D*, sample 510 taken from 20 miles beyond ends of Southwest Pass jetties in 203 fathoms of water.

did not come to the gulf through Mississippi River, at least not through the river as it is now. The sediments shown by vertical lines (Fig. 11-*A*) are the coarsest, and those shown in blank (Fig. 11-*D*) are the finest, deposited by Southwest Pass. The sediments shown by horizontal lines (Fig. 11-*B*) are intermediate in size between the coarsest and the finest of the river-borne material.

According to estimates made by Colonel Dent, Southwest Pass is lengthening at a rate of about 275 feet per year. This is seven times as fast as the present rate of growth of South Pass, although Southwest Pass

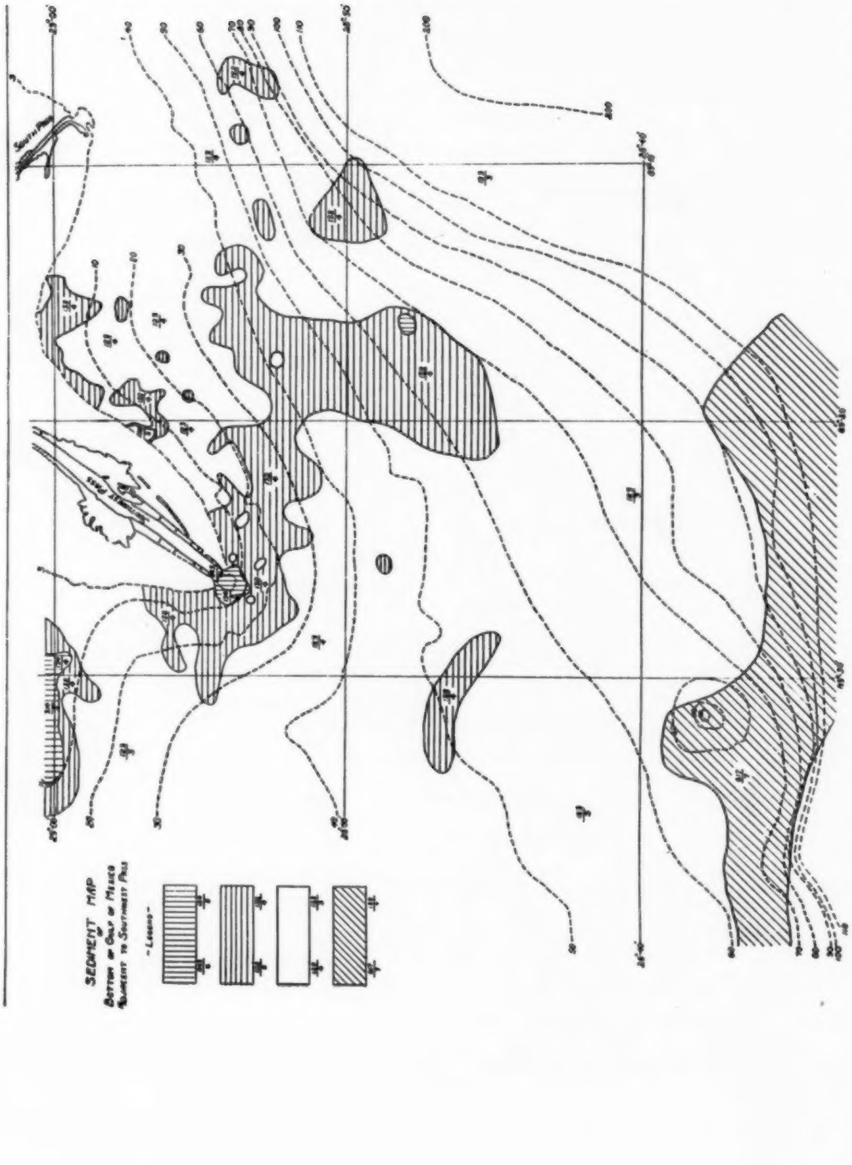


FIG. 12.—Sediment map of bottom of Gulf of Mexico adjacent to Southwest Pass. Broken contours indicate depths in fathoms.

has only three times the discharge of South Pass. Southwest Pass is being extended along a line more oblique to the gulf bottom contours than is South Pass; hence, it reaches deep water farther out. Its deposits, therefore, are not spread over quite so wide a vertical range. The gulf currents may not be quite so effective in carrying away the finer sediments from the mouth of Southwest Pass as from South Pass, due to the fact that the currents cross Southwest Pass at an angle of less than 90° and South Pass at an angle of more than 90°. It seems possible that the prevailing winds might shift less sediment westward from the end of Southwest Pass, with its northeast and southwest trend, than from South Pass, which is more exposed to the winds.

THE RIVER FROM BATISTE COLET'S BAYOU TO HEAD OF PASSES

The main river below Batiste Colet's Bayou differs from that above only in having no artificial levee, in having only low natural levees, and in having a more nearly straight course. In every flood the land is overflowed and the range between low and high stages is reduced. Consequently, no land is covered by great depths of water and the banks are not built high by the deposition of sediment. The straight course is probably due either to failure of the river here to branch as its banks were elongated gulfward, or to the natural closing of all of the passes except those that carried the water forward in a straight line.

HEAD OF PASSES

That part of Mississippi River from which water is distributed to Pass a Loutre, South Pass, and Southwest Pass, is known as Head of Passes. Although it is not possible at this time to state with confidence the precise manner in which the three passes and Head of Passes were formed, two hypotheses seem more reasonable than others that have been considered.

It seems reasonable to suppose that a branching arrangement of channels, banks, and bays may have been blocked out beneath the gulf water when the main mouth of the river was where Head of Passes now is, just as similar patterns are in process of formation near the outer ends of Batiste Colet's Bayou and Cubit's Gap to-day, as previously explained, and that these three passes persisted after other mouths had closed.

Dent[1] has shown how an outlet develops a "bell mouth," deposits a bar in its middle where the main current is, builds this bar

[1] E. J. Dent, "Notes on the Mouths of the Mississippi River," unpublished report.

to form an island, and then branches around the island, dividing into two passes. If this method of branching be used as a possible explanation for Head of Passes, the formation of two islands making one pass between them and a pass on the outside of each island would have to be assumed.

THE BAYS

In the angles between the mouths of the river below Head of Passes there are shallow bays that cover important parts of the subaqueous delta.

Jackass Bay, which is more a pond or lake than a bay, inasmuch as it is no longer connected directly with the gulf, occupies the angle between Pass a Loutre and Southeast Pass. The water is fresh. Land has been built entirely around the enclosure, by Pass a Loutre on the north, by Southeast Pass on the south and west, and presumably by some old bayou from one or the other of these passes on the east. There is now little open water in the bay, chiefly because of filling, which is still in progress by Jackass Bay Crevasse and to a smaller extent by a bayou from Southeast Pass. Almost the whole bay is a maze of shallow, bifurcating bayous, sand and mud flats, and islands.

Blind Bay is a considerable body of water between Pass a Loutre and Southeast Pass at and near their outer ends. It is open to the gulf, but the water is freshened by circulation from Jackass Bay with which it is indirectly connected, by Little Canal and Straight Bayou from Pass a Loutre, and by English Bayou from Southeast Pass. The water varies from 2 to 6 feet in depth. Bottom material is soft blue mud back of a long sand flat extending into the bay from Northeast Pass on the south. It is believed that such mud, which is very common in all the bays, includes the finest materials carried by the river water. The sands and silts are left directly at the mouths of the bayous or on the back edges of the natural levees and only the clays and colloids are carried out into the bays in appreciable quantities. Deposition is finally accomplished by slow settling of the clay and by flocculation and settling of the colloids.

Redfish Bay lies between Southeast Pass on the north and east and Balize Bayou land on the west. Its mouth is narrow and is partly blocked by the Southeast Pass mud lumps. With the exception of Loga's canal from Southeast Pass and Balize Bayou, there are no open bayous conducting river water to this bay. Consequently, the water is brackish. Oysters are grown in many bedding grounds. The bay is reported to have been considerably enlarged in recent years. At least, the head was once

prairie. Clumps of cane left as remnants are noticeably bent to the west, suggesting struggle with strong east winds. Both settling and the severe storms of recent years, the worst of which was in 1915, may be responsible for the enlargement. The water varies from 3 to 5 feet in depth. The bottom is blue mud to an unknown depth. It might be expected that the fine sediment laid here in brackish water would differ in some respects from that of Blind Bay, which is fresh, but no conspicuous differences are observable in the collected samples. It should be borne in mind in connection with all such questions that the salinity of water in all the bays is subject to considerable changes. For example, Blind Bay is probably salty or at least brackish at some seasons of the year and Redfish Bay doubtless has normal oceanic salinity at times.

Garden Island Bay is bounded on the west by the east bank land of South Pass, on the north by the Pass a Loutre Crevasse land, and on the east by Southeast Pass and Balize Bayou lands. It is open toward the south. The water of the bay is everywhere less than 10 feet deep and in most places it is less than 5 feet deep. It is freshened along its north and east shores by waters from Pass a Loutre Crevasse. In many places, at many times, the water is both fresh and salt, the salt water being at the bottom. In its outer parts the bay is salty from top to bottom. The blue mud which is found everywhere in the bay, but blanketed at different depths by layers of silt or fine sand, is believed to be the finest suspended sediment carried by the river and the colloidal materials. Both get past the mouths of the passes and across the natural levees to be deposited by flocculation or otherwise. Soft gray mud that covers the blue mud in places is the most recently deposited and has not yet been compacted and discolored. A quart jar of flocculated gray mud which was permitted to stand in the laboratory was found after a day or two to have become blue and more compact. The resulting sediment could not be distinguished from the blue mud of the bays. The thin sand layers are the result of river floods by which the coarser grades of sediment are carried farther out than normal.

East Bay occupies the angle between South and Southwest passes. It varies from 1 foot to 8 feet in depth, is generally mud-bottomed, and is salty. There are two parts separated from it by name: Whale Bay, partly enclosed by Grand Bayou land and Cowhorn's Reef, and Portage Bay, an extension toward Head of Passes. Although most of the sediment at the bottom is blue mud (Fig. 13), in many places containing shells, there are several places, especially near the shores, where the mud is covered with sand of varying thickness. Between the west jetty spit

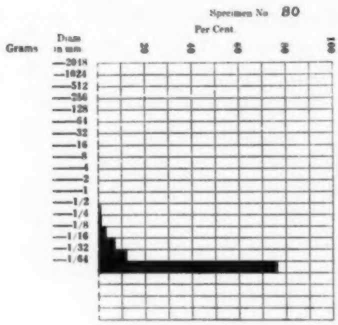


FIG. 13.—Mechanical analysis of sample 80, a typical mud from East Bay.

of South Pass and Cowhorn's Reef the bottom is generally sandy. There is also some sand in Whale Bay, inside Cowhorn's Reef, although the southern extremity of the bay has a muddy bottom. Along Southwest Pass on the west side of the bay, a sand beach extends from the outer end of the east jetty to and a little beyond a position east of Burrwood. Offshore from this beach the bottom is sandy. In the downstream angle between South Pass and Grand Bayou lands, the following materials were found:

Thickness	*Material*
1 inch	Flocculated mud
6-8 inches	Soft blue mud
6 inches	Sand and mud interbedded
8 feet or more	Blue mud

At 60 feet offshore opposite telephone pole No. 310 above the head of Grand Bayou, a little flocculated mud overlies black, carbonaceous mud with no sand between. In Portage Bay, which is everywhere less than 4 feet deep, the bottom is soft and muddy, except at some places along the shore where there is sand. In the middle part of East Bay the bottom material is mud.

West Bay lies west of Southwest Pass land and south of the mouths of the Jump. It is wide open to the gulf. With the exception of its extreme north part, which is freshened by the Jump, the water is salty. The depth of the water ranges from 1 to 10 feet. Bottom sediments in West Bay are similar in all respects to those in East Bay. Sand is interbedded with mud along the shores. Elsewhere fine, gray, flocculated mud grades downward into more compact, darker-colored, older bay mud.

MUD LUMPS

Partly because the mud lumps which are found near the main mouths of the three main passes are not now believed to be important from the standpoint of navigation, and partly because they have previously been studied in some detail by Shaw,[1] little investigative work was done on them by the writer. Shaw's explanation of them seems to the writer to be correct, at least in the main.

Since Shaw's work was done, some mud lumps have been destroyed by waves, some new ones have been formed, some have been land-tied, some which were active have become dormant or dead, and doubtless some which were dormant have again become active. Several new lumps have appeared west of the end of South Pass. In 1922, Pelican Lump, west of the Southwest Pass jetties, was rapidly being eroded. The Pass a Loutre lumps appeared to be not as active as described by Shaw. Two mud lumps, now so degraded by waves as to be exposed only at low tide, which are fully a mile southwest of the end of Balize Bayou, doubtless indicate approximately the former position of the mouth of the bayou. The bayou land must have been cut back for a considerable distance since the outlet ceased to build out its banks and bar.

Samples were taken from the surfaces of mud lumps belonging to several groups, of which a typical one is shown in Figure 14 as a matter of record.

BOTTOM SLOPE OF RIVER

Because the bottom of Mississippi River for 150 miles or more above its mouths is below sea-level, it is commonly stated in textbooks that the

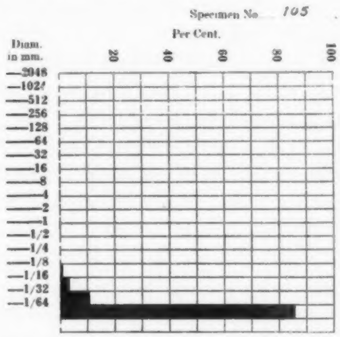


FIG. 14.—Mechanical analysis of sample 105, typical of mud-lump materials.

[1] E. W. Shaw, *U. S. Geol. Survey Prof. Paper 85-B.*

river *has cut* its valley below sea-level in this part of its course and that all streams may do the same. It must be remembered, however, that this is true of Mississippi River only on its delta where deposition and not erosion has been and is in progress.

On the delta, so far as the bottom is concerned, the water actually flows up-hill. At New Orleans the bottom in mid-channel is about 80 feet below sea-level, the crests of the bars over which the water flows into the gulf are 1-15 feet below sea-level, and the river flows up a slope of about 8 inches to the mile on the average.

A special study was made of South Pass in this regard. The mean depth, a short distance below the head of South Pass, has always so far exceeded the mean depth over the bar at the mouth that a fairly steep bottom slope upstream has been maintained. In 1922 the undredged bottom sloped from 10 feet below sea-level on the crest of the bar to 70 feet below sea-level at the head of the pass 13 miles away, recording an average upstream bottom slope of 4.6 feet per mile. The slope is neither uniform, however, nor everywhere in the upstream direction, for there are deep pockets in several places. Obviously the reduction of the bed of the river below sea-level on the delta is not due to river erosion in the carving out of the valley, but to the rehandling of previous deposits as the offshore bars migrate gulfward.

In most "graded" streams, there is a delicate balance among volume, velocity, gradient, and load. A graded stream may be defined as one which, with a specified volume, has the lowest gradient over which it can flow and carry its load. The total potential energy of any such stream depends upon its volume and its gradient, provided the added mass of load is neglected. There is so much mass falling through so much vertical distance. This energy is first drawn upon to overcome friction and to maintain flow, the energy required depending upon volume and the slope of the channel. The greater the volume of the stream the easier it is for it to flow, other conditions being equal.

The problem of the effect of the load on the energy is complex and has never been satisfactorily solved. Energy is thought to be necessary for the "transportation of the load." Energy is surely consumed in putting the load in motion, but, when moving, the load may actually contribute to the energy. The suspended load doubtless increases the viscosity beyond that of unloaded water, thus causing more friction which must be overcome in the maintenance of flow. However, the load adds weight and volume to the water, thus increasing the mass and the total energy. It is generally supposed, by geologists at least, that

the suspended load in most streams is a net drain on their total energies, although the writer knows of no published proof of the verity of the supposition. Gilbert,[1] who has made a most careful study of the mechanics of running water, has pointed out that with the addition of load to a stream of specified volume and gradient, the first effect might be increased velocity. The inference is, however, that he believes that in general the energy of the stream is used up in the transportation of its load. Indeed Gilbert expresses his opinion on this point in regard to Mississippi River, on page 267 of his paper, as follows.

> Mississippi River between Cairo and its mouth has, at flood stage, such velocity and slope that any suspended particle of silt which would sink in still water faster than half an inch a minute retards the current more through the work of suspension than it accelerates the current through the addition of its mass to the mass of the stream.

The lower limit of rate of settling of ½ inch per minute would not apply without change for those parts of the lower river whose slopes are gentler than the average slope from Cairo to the mouths, the textural limit being lower where the slope is gentle. It could probably be said regarding South Pass, however, that any sediment which could settle in still water faster than ¼-½ inch per minute would be, in its transportation, a drain on the total energy. As a very large proportion of the total load sinks more rapidly than this, it may be concluded that South Pass expends some of its energy in transporting its load. It should be noted that the texture of the load is at least as important in this connection as the amount of load.

What energy an ungraded hypothetical stream of specified volume, gradient, and load has in excess of that necessary to flow and carry its load is expended in the development of velocity. A deep stream of specified volume and load flows more swiftly over a bed of specified gradient than a more shallow one, all other conditions being the same, because the frictional surface is greater. Similarly a lightly loaded stream of specified volume and gradient flows more swiftly than a heavily loaded stream.

But in the natural graded stream it is always possible, as velocities increase or decrease, for the stream to pick up or deposit load and thus in time to reduce or increase the gradient, thus automatically adjusting the velocity to fit the conditions. In the mechanics of graded streams there are several variables, including volume, erodibility of channel, velocity, character and amount of load, gradient, and form of cross section, and no one can be changed without effect upon each of the others.

[1] G. K. Gilbert, "The Transportation of Débris by Running Waters," *U. S. Geol. Survey Prof. Paper 86*, pp. 225-27 and 246-47.

Even near the mouths of rivers, where bottom slopes are reversed in direction, there is believed to be no change *in principle* from the preceding statement. More energy would be required for South Pass to flow with a specified load up a bottom slope of 4 feet per mile than up a slope of 2 feet per mile, from its head to the crest of its bar. In flood stage the river is able to flow and carry its load up a steep bottom slope and it deepens its channel, thus acquires more load, and at the same time adjusts its reversed gradient. When the flood subsides, deposition takes place, the load is reduced, and the upstream slope of the bottom becomes gentler. Surveys by United States engineers show that, in the history of South Pass, the depth and upstream bottom slope have varied with the discharge, according to the principles here outlined.

Although it is not possible to define South Pass without qualification as a graded stream, it is believed that the principles outlined apply to it at least in so far as variations in depth with variations in discharge are concerned.

DISCUSSION

DONALD C. BARTON, Houston, Texas: I should like to ask Professor Trowbridge his reaction to two tentative working hypotheses.

The significance of the long arm-like projection of the Mississippi delta below Pointe a la Hache has been puzzling me. Uplift of about 20 feet is shown along the Texas coast and along the southwest Louisiana coast. That uplift in the Corpus Christi area has just been described by Dr. Price. It is indicated also in Orange County, Texas, and in Cameron and Calcasieu parishes, Louisiana. It is not, to my knowledge, clearly indicated farther east, but, on account of the deltaic activity, evidences of it might be very obscure. The first tentative hypothesis upon which I have been meditating for some time is that the long arm-like extension of the Mississippi River delta into the gulf below Pointe a la Hache represents the modern extension of the Mississippi River delta into the gulf below Pointe a la Hache built since that uplift.

The second tentative working hypothesis concerns the correlation of the rest — the main part — of the Mississippi delta with a set of ancient, probably late Pleistocene deltas of Trinity and Brazos rivers respectively, in southeast Texas. Recent studies of mine, the results of which are described in my paper which is being published by the Geological Society of America and the results of which also are mentioned in a paper of mine read by title on this program, show that the surface expression of the whole of Jefferson County, probably most of Liberty and Chambers counties, most of Harris County and of east Brazos County, and probably a large part of Galveston County, is that of an ancient delta of the Trinity and an ancient delta of the Brazos. Each delta is large areally and even if only a veneer on an uplifted marine plane, each of these deltas represents a very large amount of delta-building activity, which is in strong contrast to the small amount of delta-building activity manifested both by the modern Trinity River and by the modern Brazos River.

These ancient deltas are definitely post-Pliocene, definitely belong to older stream systems than the present Trinity and Brazos river systems, and definitely belong to a period of Gulf Coast geological history which has now passed. The tentative working hypothesis which has just been suggested by Professor Trowbridge's description of the Mississippi delta is that the main broad delta of the Mississippi is an ancient delta of Mississippi River equivalent to the ancient Trinity and Brazos deltas and represents a past period of much greater delta-building activity on the part of Mississippi River than at present. Mississippi River, of course, differs from the Trinity and Brazos in that the diminishing delta-building activity and the deposition of the material have continued throughout much of the delta, although the amount of delta-building activity has been reduced perhaps to a small part of what it was at the time when most of the main delta was built.

The offshore banks, on which is found the coarse sand mentioned by Professor Trowbridge as not belonging to the Mississippi delta, are striking physiographic features of the offshore bases of the Texas-Louisiana coast. They produce the anomalous situation that within 50 miles offshore the normal relief is more rugged than for 75 miles or more inland. These banks are a more pronounced feature than the present shore line and no feature of equal prominence is reached inland until the Hockley Scarp is reached. (See profile in forthcoming "Surface Geology of Southeast Texas.")

A. C. Trowbridge: I am sorry to say in reply to the first question raised by Doctor Barton that in my opinion the Mississippi delta gives no clear evidence of having been uplifted after a large part of it was built and of having been subsequently enlarged to a slight extent. It is true, of course, as pointed out by Doctor Barton, that the older and much the larger part of the delta is above Pointe a la Hache and that the smaller and younger part that is below Pointe a la Hache takes the form of a long and rather narrow projection of the delta into the gulf. It is also true, I think, as explained in my paper, that before this projection was built the main river discharged eastward toward Chandeleur Islands and built Bayou la Loutre land, which almost separates lakes Borgne and Ponchartrain from the gulf. However, I can see no evidence that this older part of the delta was uplifted before the newer part was deposited, or that the sediment of the newer part lies in any way unconformably on the older part. Indeed, the sediment and topography above and below Pointe a la Hache seem to me to have resulted from one continuous process of delta building.

In regard to the offshore submarine elevations, Doctor Barton has expressed the facts correctly. The gulf bottom has greater relief than the adjacent land surface. The dome mentioned in my paper is one of many similar and similarly located elevations of the Gulf Coast of Texas and Louisiana. Although I have little basis for judgment, it seems to me that they are more probably diastrophic or even perhaps volcanic than gradational.

PHASES OF SEDIMENTATION IN GULF COASTAL PRAIRIES OF LOUISIANA[1]

R. A. STEINMAYER[2]
New Orleans, Louisiana

ABSTRACT

The geology of the recent material of the Gulf Coastal Prairies of Louisiana resolves itself, primarily, into a study of its various phases of sedimentation, especially with respect to its environment phase.

The homogeneity of sedimentation, in the area as a whole, seemingly ends with its indefinite products. It therefore becomes futile to assign to them definite time or structural limits.

The gulf coast sediments and environments are more or less unstable, and if the latter change, the former must undergo alterations to tend toward conditions of greater stability. Some changes are sudden and erratic, others oscillate, but most of them occur slowly and in an orderly manner.

The more characteristic environmental changes occurring in the humid Gulf Coastal Prairies of low relief are changes of the environmental types and changes within the type environments.

Environment is the most important phase of sedimentation of the Gulf Coastal Prairies of Louisiana, and a better understanding and differentiation of its multiple changes and accompanying reactions of its sediments and facies organism will ultimately lead to the integration and subsequent correlation of the sequence of deposition of its material.

INTRODUCTION

The character, attitude, and distribution of the recent deposits of the Gulf Coastal Prairies of Louisiana vary considerably in different localities, during the same period of time, due to differences in the origin, transportation, and region of deposition, although gradual transition, either from one type environment to another or within the type environment in the same locality during different intervals of time, commonly produces sediments so similar that it is almost impossible to separate them.

The homogeneity of sedimentation, in the area as a whole, seemingly ends with its indefinite products, those alternating beds of gravel, sand, silt, and clay with their varying amounts of associated organic matter, and it is futile to assign to them definite time or structural limits.

[1]Read before the Association at the New Orleans meeting, March 20, 1930. Manuscript received by the editor, March 3, 1930.

[2]Assistant professor and head of the department of geology, Tulane University.

A study of the geology of the recent material of the Gulf Coastal Prairies of Louisiana is, therefore, at present primarily a study of phases of sedimentation, especially with respect to environment.

Phases of Sedimentation

ORIGIN

TERRIGENOUS SEDIMENTS

The terrigenous sediments of Louisiana are derived mainly from the destruction of older igneous and sedimentary rocks in the great Mississippi Basin (Fig. 1), comprising all or parts of 31 states, or 41 per cent of the area of the United States, extending from the Appalachian range on the east, the Laurentian highlands on the north, and the Cordilleran range on the northwest.

ORGANIC SEDIMENTS

The extensive low, flat, featureless fresh- and salt-water marshes in southern Louisiana, with their luxuriant and rapidly growing vegetation, form ideal conditions for the activity of organisms which either accelerate decay, forming new organic compounds, or assist in the generation of toxic products which arrest biochemical decomposition and preserve some of the original substance.

The rapidity of growth and accumulation of vegetation generally, however, smothers the underlying material by excluding air or aerated water and conserves the toxic products, with the resultant conservation of the raw material.

Recent borings and investigations of the surficial material in the marshes adjacent to Sweet Lake, Cameron Parish, Louisiana, have shown that there is a peat-clay formation approximately 5 feet thick, with a gradual downward transition from peat to peaty clay, the percentage of organic compound decreasing with the depth. That this material has accumulated very rapidly is attested by the complete filling of a former tidal channel 5 feet deep, behind a sheet piling, where it formerly intersected the Sweet Lake Canal. This obstruction was placed there approximately 45 years ago.

Furthermore, organisms, by reacting with chemicals in the water, may bring about deposition of mineral matter from solution, such as calcium carbonate and iron either in the form of a hydroxide, by iron bacteria, or hydrous sulphide, by the reaction of hydrogen sulphide liberated by bacteria, and other minerals.

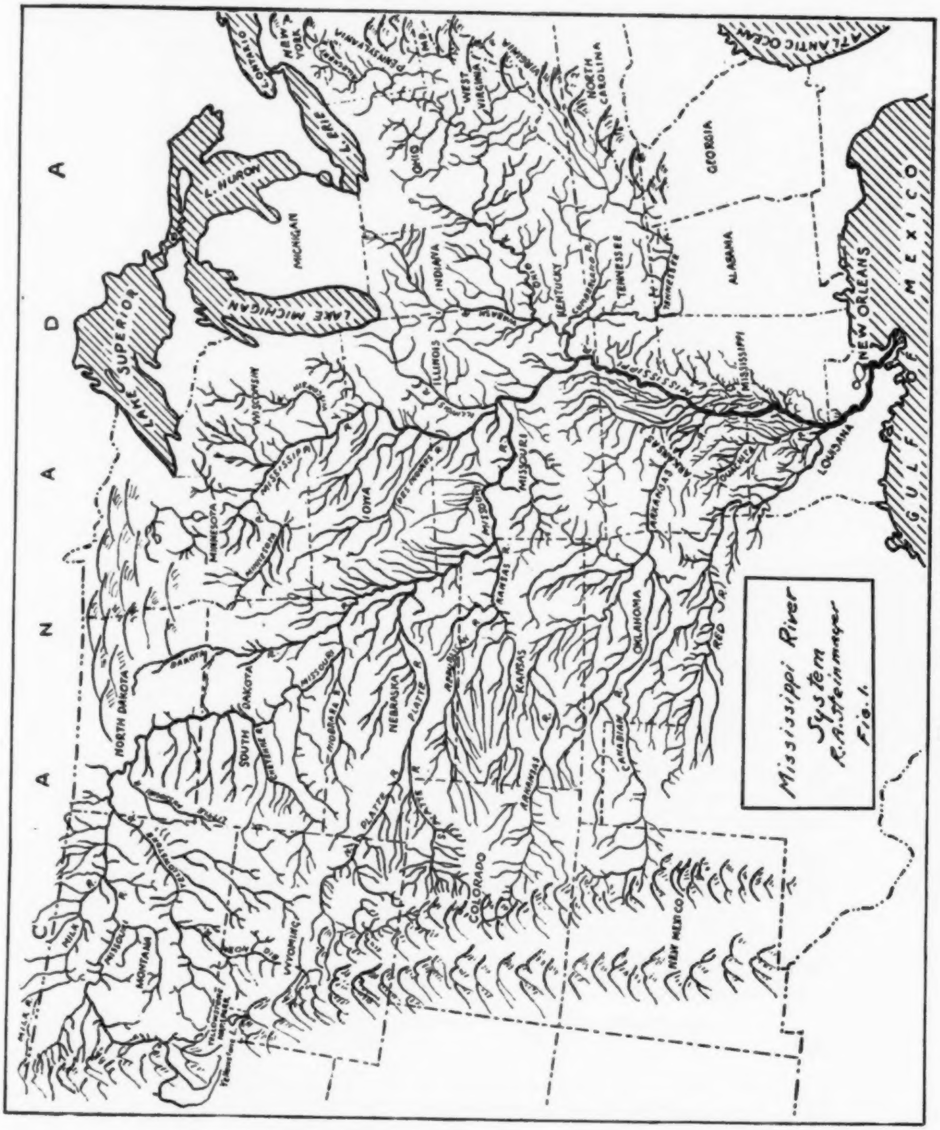


FIG. 1.—Great Mississippi River system.

TRANSPORTATION

More than 500,000,000 tons[1] of eroded material from other states is annually transported by the "great sewer," Mississippi River, alone, and subsequently deposited on the "general dumping grounds of the nation." Along its gulfward margin, tidal and shore currents and wave action perform a significant part in assorting and re-working this material or in the transporting of new material for the building of barriers that ultimately land-lock the gulf waters behind them.

In humid areas, rain wash may, at times, very effectively transport sediments with its sheet waters from one locality to another. In New Orleans and adjacent areas, on Good Friday, 1927, a torrential rain precipitated 14 inches of water in 19 hours, almost inundating the entire

[1]The following data were submitted by John L. Porter, chemist for the Sewerage and Water Board, as compiled by him and W. B. Gregory, professor of hydraulic engineering of Tulane University.

Sediment amounting to 60,000 tons is annually removed from a daily volume of 48,000,000 gallons of Mississippi River water.

Percentage, by weight, of suspended matter in the water—0.0065.

ANNUAL RIVER DISCHARGE

	Second-Feet
Minimum of Upper River	200,000
Maximum of Upper River*	2,000,000
Mean of Upper River	800,000
Minimum at New Orleans	135,000
Maximum at New Orleans	1,360,000

*At latitude of Old River, 2,336,000 second-feet (1927 flood confined); at latitude of Old River, 2,650,000 second-feet (1927 flood confined) maximum; from *Spec. Rept. Mississippi River Com.* (November 28, 1927), Table 17, p. 51.

From the foregoing data one may calculate the following.

Annual amount of water taken from the river by the Sewerage and Water Board, 17,520,000,000 gallons or 2,336,000,000 cubic feet.

With a mean discharge of 800,000 second-feet annually, there will be a discharge of 25,228,800,000,000 cubic feet of water near Old River. With this information and the data submitted by Mr. Porter it is comparatively simple to work out by proportion the total amount of sediment transported by the Mississippi past Old River.

60,000 tons: 2,336,000,000 cu. ft. :: X tons : 25,228,800,000,000 cu. ft.

X equals (approx.) 650,000,000 tons

Checking by per cent:

$$\left.\frac{25{,}228{,}800{,}000{,}000 \times 62.5 \times 0.0065}{2{,}000}\right\} 510{,}000{,}000 \text{ tons}$$

In the foregoing calculations, however, the specific gravity of the material in suspension is considered the same as water, although in reality it is slightly greater.

city and adjacent areas. Much of this water outside of the city was disposed of as run-off water carrying with it the agitated suspended material to near-by lakes, bayous, and rivers.

Organisms, both plant and animal, not only assist in modifying the sediments, but also assist in displacing them. The elaborate system of levees that ramify throughout the state, the hundreds of millions of dollars that have been spent, and the tens of millions that must annually be appropriated for defensive purposes in Louisiana against the agencies of nature, principally running water, are mute testimony of man's activity in this work. Other organisms, such as the burrowers (muskrat, crayfish, and earthworms), the borers (sponges, gastropods, pelecypods, and insects), vegetation, principally of the floating type, such as the Red River rafts and the matted water hyacinths, are only a few examples of the organisms that assist man materially in this work.

If we add to the materials displaced by rivers, waves, land creep, rains, organisms, winds, and less important transporting agencies, the material deposited in standing inland bodies of water, the sum of all the material moved, within the state, will exceed 1,000,000,000 tons.

PRINCIPAL ENVIRONMENTS OF SEDIMENTS

The Gulf Coastal sediments and environments are more or less unstable and if the latter change, the former must undergo alterations toward conditions of greater stability. One environmental factor does not change without influencing others. Some changes are sudden and erratic, other oscillate, but most occur slowly and in an orderly manner.

The more characteristic environmental changes are changes of the environmental types and changes within the type environment.

Changes within or from one environmental type to another ordinarily not only modify the sediments but also have a corresponding influence on the organisms that live within them. That such changes have had a marked influence on the ecologic distribution of previous recent life is attested by their records in their sediments. The climactic formations of organisms were either successively blotted out when the factors varied beyond their maximum limit of toleration, or they feebly attempted to migrate through the highways, commonly tidal channels, to a more favorable place where they sought to reach a more harmonious relation with their environment, but generally died in the attempt.

Sediments have been classified by Twenhofel,[1] according to their surroundings, into three environments, namely, continental, mixed con-

[1] W. H. Twenhofel, *Treatise on Sedimentation*, National Research Council of the National Academy of Science, Chap. VII.

tinental and marine, and marine. Each of these, in turn, may be subdivided into type environments, to designate the essential characteristics of the former, such as the lacustrine type of continental environment. The type environments having water mediums should be further classified upon the bases of the differences in the composition of their mediums into the fresh-, the brackish-, and the marine-water phases.

The important environments and subdivisions thereof, in the Gulf Coastal Prairies of Louisiana, may be classified as follows.

- Continental environment
  - Fluvial type
  - Lacustrine type
  - Paludal type
- Mixed environment
  - Delta type
  - Marginal lagoon type
  - Littoral type
  - Tidal channel type
  - Embayment type
- Marine environment
  - Neritic type

CONTINENTAL ENVIRONMENT

FLUVIAL TYPE

The fluvial type includes sediments modified and deposited by running water, and, because of the arbitrary separation below the distributaries of Mississippi River, sediments of this type extend into sediments of the delta type of mixed environment, their phasal medium remaining essentially a fresh-water medium, although this is but a relative term and does not imply that the composition of the water is the same at all times. Tides are known to have affected the substratum of Mississippi River as far upstream as New Orleans. The preponderance of the fresh-water deposits, at least of the surficial deposits, in the embayment area, laid down since the contraction and gulfward withdrawal of the transgressing waters to the present gulf shore line, clearly illustrates the importance of the fluvial type of environment in the reclamation of the embayment area.

All of the meandering gulf coastal streams are characterized by marked variations in the stages of their water, and upon this basis they may be classified into two stages, namely, (1) the channel stage, characterizing those sediments deposited within the channel, and (2) the flood-plain stage of those sediments outside of the channel.

Channel stage.—Many disturbing conditions occur in streams that have essentially reached their base level, tending to keep them in unstable equilibrium. Irregularities or obstructions in their channels, however slight, induce oscillation, and, the action being continuous, the effects are cumulative, and the oscillation increases until it reaches a mean between the force of gravity tending to direct the current in a straight line, and the forces of deflection tending to give a direction more or less at right angles to the former. Due to many irregularities, the gulf coastal rivers flow in a series of meanders that bear a definite relation to their volume, gradient, and head; and their axes of greatest velocity alternately cross the stream and commonly set up counter currents.

The preceding generalities, in regard to the behavior of meandering streams that are near their base level, apply mainly to the smaller coastal rivers and may be applicable to the Mississippi during its low-water stages. If the extreme annual differences in the discharge of its waters are taken into consideration, varying from a minimum of 200,000 second-feet to a maximum of more than 2,000,000 second-feet (flood-waters confined), one can readily realize that much about its behavior is still unknown and it may be aptly termed the "river of problems." The channel of the Mississippi near New Orleans has a depth of 229 feet, and, what is more extraordinary, the river at that point has double the average cross section. The elevation of the water has varied from 1.6 feet below mean gulf level to 21.2 feet above mean gulf level.

One of the most important principles of stream sedimentation is that flowing water assorts the débris delivered to it.

Flood-plain stage.—The flood-plain stage of sedimentation is characterized by those deposits laid down in flood waters which have spilled over, broken through, or boiled up behind the levees, during flood stages of the rivers. Generally when these waters spill over or flow through a considerable break of the levees, especially if the land they inundate is poorly drained, featureless, low, and of gentle slope, they quickly lose their initial velocity, deposit the coarser and heavier sediments, and build up ridges near and parallel with the channels, thence spread themselves out, and move over considerable areas as a water sheet or sheets of low competency; consequently they transport, affect, and subsequently deposit only material carried in suspension and solution. The character of the sediments during, and subsequent to, their deposition may be changed directly or indirectly by the associated transported and indigenous organic matter so plentiful in the flood-plain areas.

It has been estimated that the surplus water of the flood of 1882 could be retained in a reservoir of the size of the state of New Jersey if of a depth of 15 feet.[1]

Flood waters breaking through constricted gaps in the levee, slightly above the distributaries, generally have high velocities and may erode, in a very short period of time, new channels of considerable depths (Nita Crevasse). Such breaks are termed "crevasses" in the gulf coastal terminology.

The Nita Crevasse which occurred in 1890 reached a discharge of 402,556 second-feet, yet flood stage at Carrollton, about 58 miles below, was lowered only 1.6 feet. The crevasse carried about one-third of the discharge of the entire river.

At the time of the break the crevasse was approximately 600 feet in width by 15 feet in depth, the width rapidly increasing to 3,000 feet.

The Colorado River, which created such havoc in the Imperial Valley of California, has a maximum discharge of 150,000 second-feet, or about one-third of the Crevasse. The Niagara River, which, with its cataracts and rapids, is one of the wonders of the world, has a normal discharge of about 200,000 second-feet, or one-half of the discharge of the Nita Crevasse.[2]

Deposits laid down in waters of this specialized type are only local in character and can not be separated from those of the channel type.

Sand boils are of little environmental importance, so far as sedimentation is concerned, but from the flood-control point of view they are generally prophetic of breaks in the levees.

The material laid down on the flood plains may be subsequently transported and "piled up" into rectilinear dunes. Lowe[3] states that the loess deposits of the state of Mississippi originated in this manner.

LACUSTRINE TYPE

Innumerable lakes of various modes of origin and development are distributed throughout the coastal prairies of Louisiana and their environments. Those originating within the continental environment were developed principally by surface streams and, like them, in a detailed analysis, could be classified into the same two stages, depending upon whether the sediments were deposited in the cut-off meanders of their channels or in basins on their flood plains. In their incipient for-

[1] C. McD. Townsend, "Spillways," *Proc. Louisiana Eng. Soc.*, Vol. 11 (August, 1925), p. 125.

[2] J. A. Okerson, *Outlets for Reducing Flood Heights* (Mississippi River Commission, 1914), p. 8.

[3] E. N. Lowe, "Loess or Bluff Silt," *Mississippi State Geol. Survey Bull. 14* (1919).

mation their waters are fresh and the character of their sediments bears a marked resemblance to that of sediments of the fluvial type from which they originated. During the lake cycle, however, the character of the sediments and the facies type of organisms is modified or altered by dimensional changes in their basins and compositional differences in their mediums and ultimately blends into the paludal type of deposits.

Solution lakes.—In the marshes and on the mounds in southern Louisiana occur here and there small lakes that were developed principally by ground waters, some of them by the dissolving of the soluble material, leaving basins; others by a collapse of the roof of the underlying solution caverns. The former are comparatively shallow, but the latter may be very deep. The shores of these lakes are very steep. They are dependent upon a renewal of their supply of water either from rain or from springs. Their waters are generally very saline because they commonly overlie shallow salt domes. The solution lakes on Avery's Island are lakes of this type.

PALUDAL TYPE

Swamps commonly represent only the closing phases of the lake cycle; therefore, it may be impossible to draw a line of demarkation between their sediments. In the continental environment they may originate in a manner similar to lakes or they may be the results of poor drainage, impeded percolation, heavy precipitation, encroaching vegetation, or checked evaporation.

Swamps which originate from the lacustrine type of continental environment are formed chiefly by the filling of lakes with sediments carried to them by the wind, by water, or by the growth of vegetation. In the semi-tropical humid gulf coastal areas, vegetation is the dominant agent.

Like lakes, every phase may be represented in the composition of the water, but the fresh- and brackish- or stagnant-water phases predominate. They pass into the marine phase only when their waters are almost entirely evaporated.

Swamps and lakes originating within other environments and eventually surrounded by continental conditions are discussed under their originating environment.

MIXED CONTINENTAL AND MARINE ENVIRONMENT

DELTA TYPE

The land in the lower delta of Mississippi River is advancing into the Gulf of Mexico, it has been estimated, at an average rate of 300 feet

per year, although engineers believe this estimate to be applicable only to that part of the delta in front of the jetties; elsewhere, they state, it is considerably less. Furthermore, investigations have shown that, in addition to its normal growth due to the accumulation of sediments, there is a subsidence and a lateral creep of the mass. The subsidence is due principally to the weight of the superimposed delta material, producing a compression of the lower fluid strata. This action is generally noticeable only in areas devoid of overflow, due to the fact that elsewhere the annual accumulation is slightly in excess of its subsidence. E. L. Corthel[1] states:

> Two or three miles above the Head of the Passes was built, many years ago, a pilot's house on brick piers 5 feet high. The ground is now up to the sills of the house, but the surface of the ground bears the same relation to the water surface in the river as when the house was built.

Wells drilled at New Orleans have encountered standing cypress stumps in as many as three successive horizons, at various depths, below the surface. A few years ago, during the drilling of a water well for the Kentucky Alcohol Company at Westwego, Louisiana, a large fragment of carbonized cypress wood, containing oil, was brought to the surface from a depth of 610 feet. This, however, may represent submerged drift wood.

The gulfward creep of the fluid layers of sediment of low specific gravity is evidenced by time variations in the shape and the position of the shoaling deposits in the gulf bottom just off shore. Corthell also says:

> A base line along a solid island at the mouth of Southwest Pass lengthened in a few years by accurate measurement from 700 to 712 feet.

Delta lakes.—The narrow strips of levees and swamp lands that border the various passes commonly join and enclose bodies of the original gulf water in the low space between them, forming lakes, such as the many small lakes between Main Pass and Octave Pass. Blind Bay, between North and Northeast passes, will soon be enclosed and become a lake of this type. Or the delta fingers may extend back and unite with the mainland in a similar manner and form lakes similar to Lake Borgne and Lake Ponchartrain. Before their enclosure, their environment and the composition of their waters are almost identical with those of the bordering delta. After their isolation, however, they pass through a cycle of change of type environment similar to that of those originating from marginal lagoons, and, if they are not obliterated beforehand by a

[1] E. L. Corthell, "Discussion of the Reclamation of the River Delta," *Trans. Amer. Soc. of Civil Eng.*, Vol. 54.

filling process, pass into the continental environment. Lakes originating in a manner similar to the origin of Lake Borgne and Lake Ponchartrain, even after they have passed into their continental environment, may be of considerable size. Lake Ponchartrain, next to the Great Lakes, is the largest fresh-water lake in the United States.

MARGINAL LAGOON TYPE

The series of long narrow sand and shell ridges with intervening marshes and lakes, nearly parallel with the present gulf shore line and extending inland therefrom as far as Lake Charles, are evidence of the environmental history of sedimentation of southwestern Louisiana interwoven about its marginal lagoons and barrier beaches. The mechanics of their formation is familiar to every student of geology.

Origin of Sweet Lake from marginal lagoon.—Sweet Lake, Cameron Parish, a fresh-water lake of considerable size and depth among coastal lakes, may be cited as an example of a remnant of a prehistoric marginal lagoon.

With the exception of the lake-shore escarpment on the west side of the lake formed by the prevailing south-by-southeasterly winds developing a lake-shore beach (the shell banks), the present shore line is only seemingly defined by the cessation of vegetation which at some points has encroached into water of a depth of 18 inches or more.

Open connection between it and Calcasieu Lake and thence with the gulf was maintained by a meandering tidal channel, Bayou Bois Connie, until comparatively recently, as was testified a few years ago by some of the older inhabitants of that area, who traveled by boat from Calcasieu Lake through Bayou Bois Connie into Sweet Lake before the Sweet Lake termini were artificially dammed by the excavated material from the adjacent marshes during the construction of the Sweet Lake and Intra-Coastal Canals. These former termini still appear as saddles or basins in the otherwise regular surface relief of the shore of the lake, and in them are salient angles or small outward embayments of the lake water. The type of vegetation growing on what was formerly the banks of the tidal channel is quite different from the vegetation now growing in its partially silted channel. Furthermore, borings in these outlet channels show, at a depth slightly below the present lake bottom, coarse sediments that were deposited and carried there during the time of their open connections, when tidal currents had sufficient velocity to transport them.

The antecedent history of Sweet Lake dates back to the time when a shallow sea covered all of Cameron Parish and extended northward beyond Lake Charles in Calcasieu Parish, where the perimeter of its old

shore line is now marked by a surface outcrop of marine shells. Later wave action formed barrier beaches and isolated a considerable part of the seaway behind them. These beaches can be observed to-day as low ridges, one near the Cameron-Calcasieu Parish line, Hackberry-Grand Lake Ridge, and another near the southern part of Cameron Parish, Cameron-Chenier Ridge, enclosing what was formerly the Great Cameron Lagoon but which since then has been nearly filled by sediments, leaving only small isolated remnants of open water, such as Calcasieu, Sweet, and Willow lakes. Slight coastal rising may have assisted in the development of this area.

Origin of Sweet Lake from marsh fires.[1]—In contradiction, however, to the lagoonal theory in regard to its origin and normal development, plant ecologists recently offered a marsh-fire theory. This theory postulates that Sweet Lake, like James Lake south of it, was formed comparatively recently by the burning of marsh fires. These fires not only burned off the surface covering of the luxuriant vegetation, but also ignited the underlying peat and peaty clay to a depth of at least 5 feet below mean gulf level, thereby creating a basin which was subsequently filled with fresh water.

The principal weakness of this theory lies in the following facts: (1) to date no ignited peat-clay residue has been found within or near the lake; (2) neither has there been offered a satisfactory explanation of the mechanics involved in the burning of material to a depth of at least 5 feet below the ground-water table in a zone of saturation; and (3) the assumption that the small shells of the brackish water mollusk, *Rangia cuneata*, were gathered from some fossil lake in that vicinity and cast upon the ridges to form the refuse mounds, or kitchen middens, admits the former existence of a larger brackish-water lake and barrier beaches.

Origin of Sweet Lake from solution basin.—It has also been suggested that Sweet Lake may represent a solution basin overlying a salt dome. Borings and seismographic operation have definitely established the existence of an underlying deep-seated dome, but at a depth too great to assign, as the origin of a surface basin, the removal of some of its deep-seated soluble material.

LITTORAL TYPE

It is almost impossible to delimit the temporary zone occupied by shore drift in transit from the other types of mixed environment and

[1]Original of Plaintiff (No. 28,266), Supreme Court of Louisiana, State of Louisiana *vs.* Sweet Lake Land and Oil Company, Inc., *et al.*, pp. 81-108.

the neritic type of marine environment in Louisiana, because of its variable shore line and the rapid dropping off of its shelf to great depths. Any attempts, therefore, to define its land or gulf limits would be more artificial than natural. Where it occurs, principally in southwestern Louisiana, it is characterized by a narrow zone of wave activity, shore currents, and tides; consequently it tends to sort and disintegrate its material. The upper limit of this zone is exposed twice daily directly to the atmosphere; therefore it is inhabited by both marine and terrestrial organisms.

TIDAL-CHANNEL TYPE

Although tidal channels, throughout most of their length, are surrounded by the continental environment, they originated in the marine environment, and their sediments may be derived, at times and in places, from any one or more, or all, of the environments.

The entire southern part of the state is dissected by tidal inlets and thoroughfares, maintained by waves and tidal currents serving as flowing-water connectives, for considerable distances inland, at times, between the land and the gulf. These are locally termed bayous and passes. Some of them meander in their tortuous channels and eventually dissipate themselves in the marshes, but others maintain open connection between inland lakes, of either the lagoonal or deltaic type, and the gulf. They are generally characterized by their extreme depth, narrowness, and variable length. Thoroughfares such as the Rigolets between Lake Ponchartrain and Lake Borgne, with a depth of 95 feet, are much deeper than the inlets due to the constant scouring by reversing currents.

The composition of their medium is ordinarily brackish throughout most of their length, but if they extend inland for a considerable distance, it may be fresh near their land termini.

Tidal channels have been very important as migratory highways for organisms during oscillatory or transitional changes in their environments.

EMBAYMENT TYPE

The irregular shore line of Louisiana produces surroundings favorable to the embayment of the gulf waters. Some of the embayments, such as Atchafalaya Bay, are open and subject, to a limited extent, to wave action from the gulf; others, such as Barataria Bay, are almost entirely shut off from the gulf by reefs and bars.

They represent type environments of diversity as to origin, development, size, depth (although the majority are comparatively shallow), currents (both off-shore and on-shore), and the type of organisms that

inhabit them. Each embayment, therefore, becomes a separate problem of sedimentation.

MARINE ENVIRONMENT

NERITIC TYPE

The same reasons that make it difficult to define the limits of the littoral zone apply, as well, for most of the narrow shelf area of the state covered by the shallow marine waters of the gulf. As in the littoral zone, its bottom is scoured and its sediments are only temporarily deposited. They grade landward into those of the littoral type, and at its seaward limits they pass imperceptibly into the finer deposits of the deep sea. The medium is essentially marine in all places and in it live a host of shallow-water marine organisms.

Shore waves may build spits and bars such as those in Barataria Bay, being isolated by Grand Terre and Grand Islands, and the spit shown on the Cat Island, Louisiana, topographic sheet.[1] Or they may form reefs such as Robinson Reef (East Delta topographic sheet) and Birds Island (Forts topographic sheet), where the littoral currents have dropped their load in the deeper quiet waters.

CONCLUSION

Environment is the most important phase of sedimentation of the Gulf Coastal Prairies of Louisiana and a better understanding and differentiation of its multiple changes and accompanying reactions of its sediments and facies organism will ultimately lead to the integration and subsequent correlation of the sequence of deposition of its material.

[1]Issued by U. S. Geol. Survey, Dept. of Interior.

GEOLOGY OF LARREMORE AREA, CALDWELL COUNTY, TEXAS[1]

A. W. WEEKS[2]
San Antonio, Texas

ABSTRACT

The writer describes the geology of the structure upon which the Larremore oil field is located. This field is also known as the Jolly or Roxana field, as the discovery well was drilled on the A. W. Jolly farm, C. Crenshaw Survey, by the Roxana (now Shell) Petroleum Corporation. The oil is obtained from the Edwards limestone encountered at a depth of approximately 1,285 feet. This is the second Edwards limestone field discovered in the United States.

INTRODUCTION

The writer is indebted to the management of the Shell Petroleum Corporation and especially to W. van Holst Pellekaan and Angus McLeod for permission to publish this paper. J. Q. Myers kindly aided the writer in the preparation of the maps.

It is intended to describe briefly the geology of the area in which the Larremore oil field is located. This field is also known as the Jolly or Roxana field, as the first well was drilled on the A. W. Jolly farm, C. Crenshaw Survey, by the Roxana (now Shell) Petroleum Corporation.

The center of the Larremore area is approximately 3 miles west of the town of Lockhart, Caldwell County, Texas. The structure was discovered and mapped in September, 1926. The work was checked by E. G. Robinson, at that time district geologist for the Roxana at San Antonio, Texas. After a block of leases covering the structure was taken by the Roxana Petroleum Corporation, core tests were drilled to an average depth of 30 feet to locate more definitely the surface trace of the fault near the center of the structure. These core tests were drilled with a drop auger through a 30-foot mantle of gravel and alluvium which covered the Midway on the downthrown side and the Navarro on the upthrown side of the fault.

[1]Read by title before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, February 1, 1930. Published by permission of the Shell Petroleum Corporation.

[2]Shell Petroleum Corporation.

Through a combination of leases, the Humble Oil and Refining Company obtained a small interest in the block with the Roxana. Cranfill and Reynolds and Dilworth also own a small lease.

STRATIGRAPHY

The exposed formations in the Larremore area belong to the Navarro formation of the Upper Cretaceous, and the Midway and Wilcox formations of the Eocene. Overlying these formations in a considerable part of the area is a veneer of gravel of Pliocene or Pleistocene age. Recent alluvium is found along the drainage channels.

The accompanying geologic map (Fig. 1) shows the surface distribution of the formations.

The lowest formation exposed in the area is the Navarro. This formation is made up of a bedded gray clay shale and beds of yellow to gray, fine-grained, limy sandstone.

The Midway formation overlies the Navarro unconformably. The Midway is a massive gray clay shale, containing beds of limy concretions and a bed of greensand in the lower part. For convenience and accuracy in mapping the structure, the Midway was carefully divided into six parts.

The Wilcox formation overlies the Midway. It is made up of alternating beds of sand and shale. The lowest part of this formation is found in a small part of the area discussed.

The Pliocene or Pleistocene gravel in this area ranges in thickness from almost nothing to 80 feet. It contains fresh water.

The thickness of the alluvium along the stream course is nowhere more than a few feet.

The formations below those mentioned have been described in other reports concerning the general area. The log of the Roxana Petroleum Corporation's A. W. Jolly No. 1, C. Crenshaw Survey, gives the thickness and names of the formations penetrated from the surface to the Edwards limestone.

STRUCTURE

The areal distribution of the formations on the surface geologic map furnishes the key to the structure of the area.

The subsurface contours (Fig. 2) drawn on the top of the Edwards limestone correspond with the surface structure. The throw of the fault and the closure of the structure are readily obtained from the map. The accompanying cross section (Fig. 3) shows the dip of the fault plane

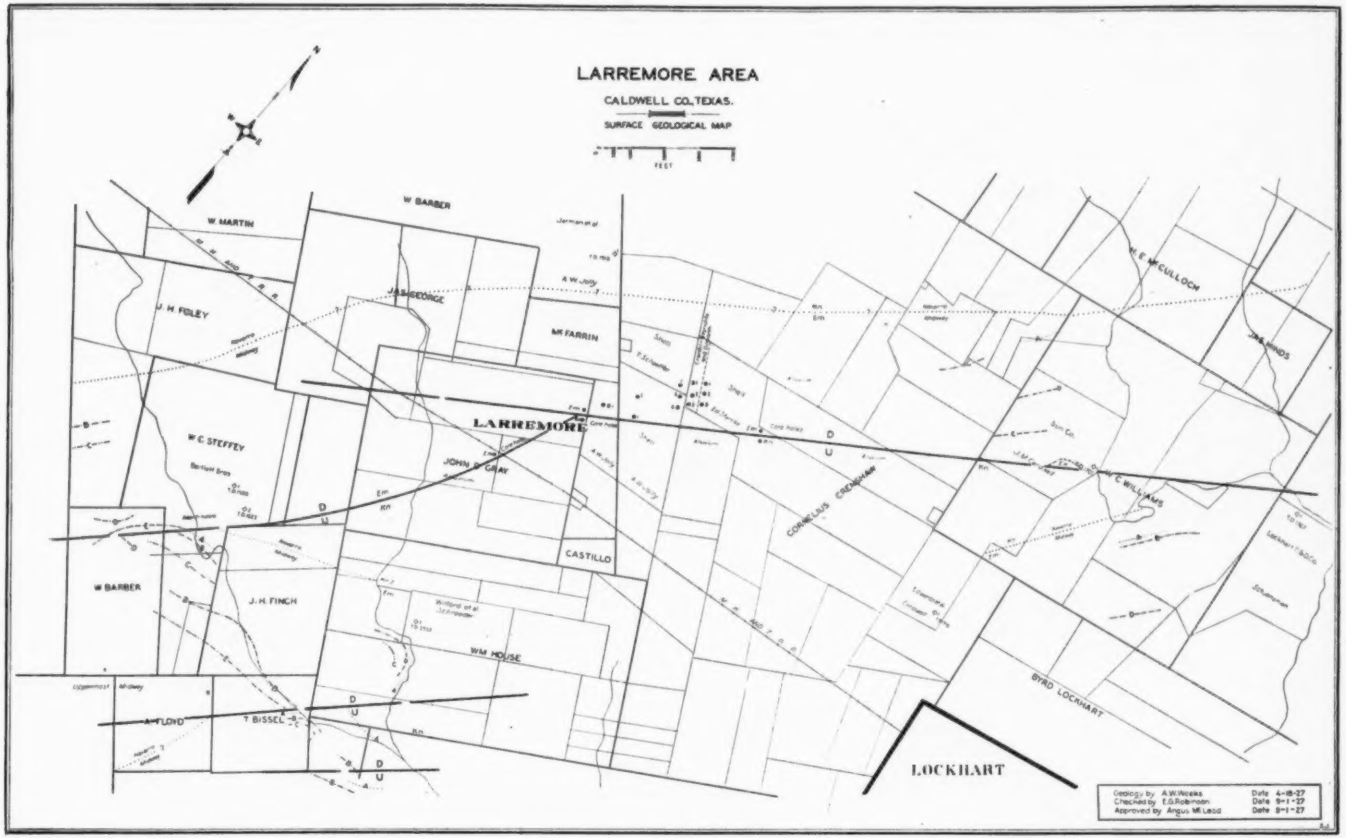

LARREMORE AREA
CALDWELL CO. TEXAS.
SURFACE GEOLOGICAL MAP
FEET
W. BARBER
W. MARTIN
J. H. FOLEY
JAS. GEORGE
M^c FARRIN
LARREMORE
JOHN B. GRAY
W. C. STEFFEY
CASTILLO
J. H. FINCH
W. BARBER
WM HOUSE
A. FLOYD
T. BISSEL
CORNELIUS CRENSHAW
H. E. M^c CULLOCH
JAS. HINDS
W. C. WILLIAMS
BYRD LOCKHART
LOCKHART
Geology by A. W. Weeks Date 4-18-27
Checked by E. G. Robinson Date 9-1-27
Approved by Angus M^c Leod Date 9-1-27

FIG. 1

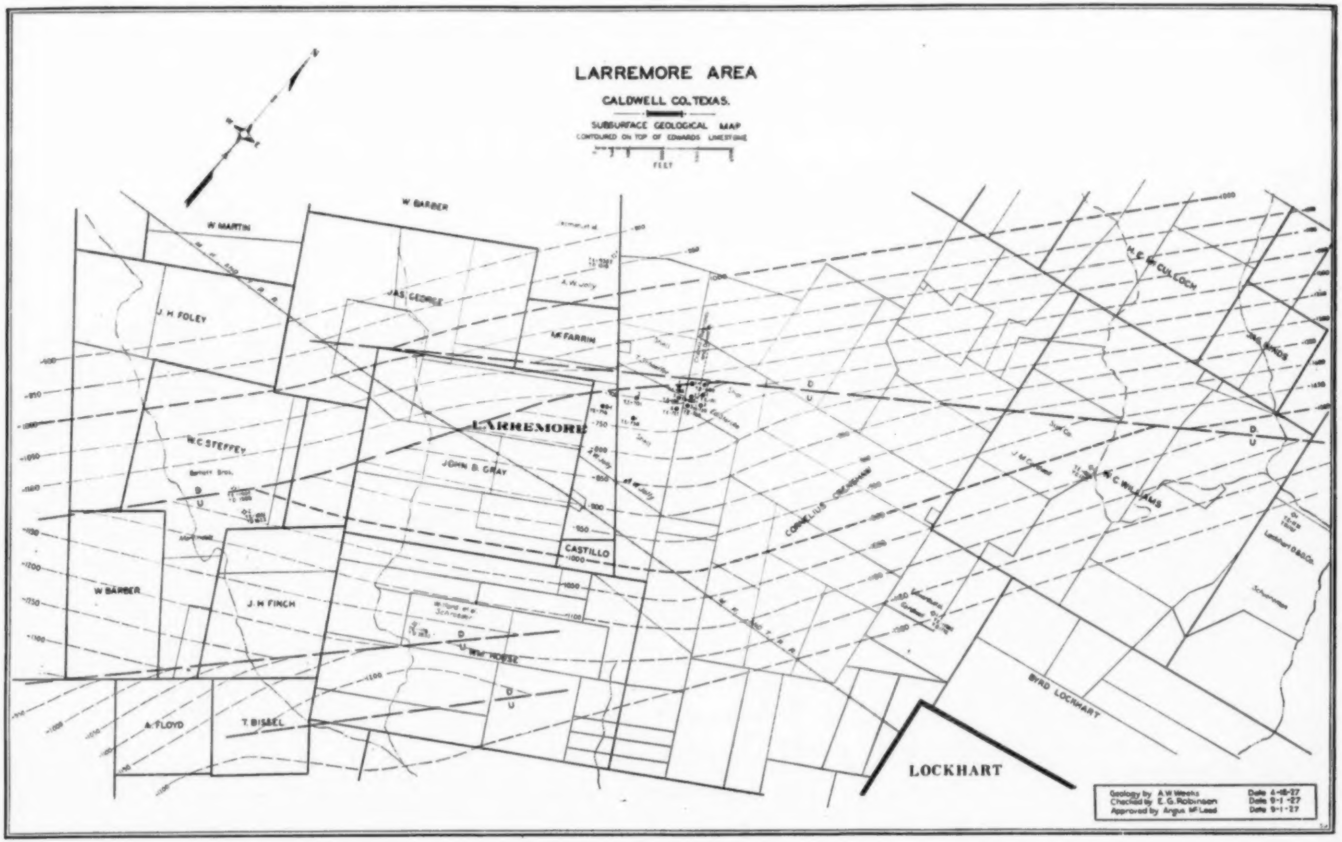

LARREMORE AREA
CALDWELL CO. TEXAS.
SUBSURFACE GEOLOGICAL MAP
CONTOURED ON TOP OF EDWARDS LIMESTONE
FEET
W BARBER
W MARTIN
J. H FOLEY
JAS. GEORGE
McFARRIN
A. W. Jolly
LARREMORE
JOHN B. GRAY
W. C STEFFEY
CASTILLO
W BARBER
J. H FINCH
A. FLOYD
T. BISSEL
CORNELIUS CRENSHAW
M. C. McCULLOCH
JAS. BINDS
W. C WILLIAMS
BYRD LOCKHART
LOCKHART
Geology by A W Weeks Date 4-18-27
Checked by E. G. Robinson Date 9-1-27
Approved by Angus McLeod Date 9-1-27

FIG. 2

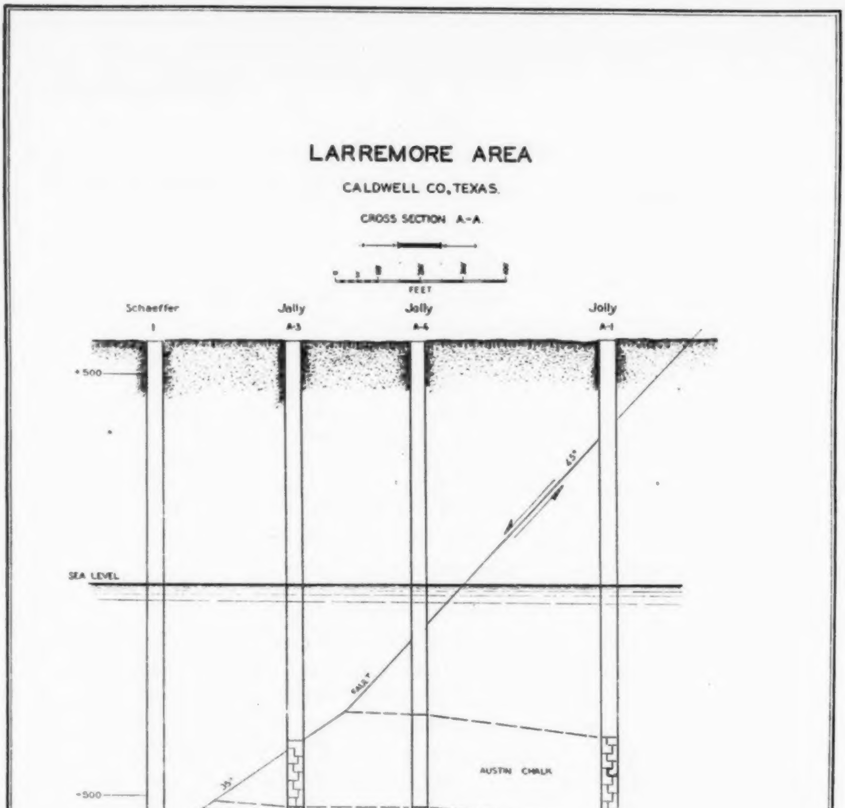

LARREMORE AREA
CALDWELL CO., TEXAS.
CROSS SECTION A-A.
FEET
Schaeffer
1
Jolly
A-3
Jolly
A-6
Jolly
A-1
+500
SEA LEVEL
FAULT
45°
35°
-500
-1000
AUSTIN CHALK
EAGLE FORD
BUDA
DEL RIO
GEORGETOWN
EDWARDS
T. SCHAEFFER
ED. STARCKE
"A"
"A"
A. W. JOLLY
A
A

FIG. 3

TABLE I

Log of Roxana Petroleum Corporation's Jolly A-1

Elevation, 572 feet. 10-inch casing set and cemented at 43 feet. 6⅝-inch casing set and cemented at 1,309 feet.

Depth in Feet (Lower Limit)	*Formation*
42	Surface soil and gravel
222	Shale and sand (Midway greensand at 180)
672	Shale
928	Sticky shale
938	Hard shale
1,150	Austin chalk
1,164	Eagle Ford shale
1,221	Buda limestone
1,270	Del Rio clay
1,307	Georgetown limestone
1,309.5	Dobie (Edwards)
1,351	Edwards limestone

near the center of the field. It is interesting to notice that it flattens after the Austin chalk is encountered.

DEVELOPMENT

Before the Larremore structure was drilled by the Roxana Petroleum Corporation, several tests were drilled near the area by companies and individuals. The Wilford *et al.* Schroeder No. 1, William House Survey, was drilled about 8,000 feet southwest of the center of the structure. It had a good showing of oil in the Edwards limestone.

The Roxana Petroleum Corporation's A. W. Jolly No. 1, C. Crenshaw Survey, was commenced May 12, 1928. It encountered the hard Edwards limestone at 1,309.5 feet and was finally drilled to a depth of 1,351 feet. Its initial production was about 25 barrels of 23.4° A. P. I. gravity oil and considerable sulphur water from porous Edwards limestone. The A. W. Jolly No. 2 was drilled 600 feet west of the No. 1. It encountered the Edwards limestone at 1,268 feet, or 37 feet higher structurally than the No. 1. It was drilled to a total depth of 1,296 feet. This well had an initial production of about 300 barrels of oil. The other wells drilled were similar to the Roxana's Jolly No. 2. The best wells soon settled to daily production varying from 30 to 60 barrels of oil and considerable sulphur water.

HENDRICK FIELD, WINKLER COUNTY, TEXAS[1]

A. L. ACKERS[2] and R. DeCHICCHIS[2]
Midland, Texas

R. H. SMITH[2]
Wink, Texas

ABSTRACT

The Hendrick field, central Winkler County, the first field to be prorated in Texas, is located in an area that at one time was thought to be the deepest part of the Permian basin. Subsurface folding is not reflected in the surface, which is covered with wind-blown sands.

The prolific production of oil is due to the high porosity in the producing limestone horizons, aided by the great hydrostatic pressure of water.

Introduction

The Hendrick field is worthy of special mention, inasmuch as it was located, at the time of its discovery, in what was thought to be the deepest part of the Permian geosyncline of West Texas.

It must be remembered that subsurface control at that time was limited to a few wells located many miles apart, some drilled into the Delaware section, and others into the so-called "Big lime."

The Hendrick field was the first field in West Texas to be placed under proration.

The average gravity of the oil is 28.7° Bé. Several wells registered slightly more than 1,300-pound rock pressure, and one well, Southern Crude Oil Purchasing Company's T-88-M-1, registered 1,620 pounds.

The largest initial production based on a 1-hour flow test was 98,000 barrels per day from Cranfill and Reynolds' Hendrick C-1, located in Sec. 33, Blk. 26.

On February 1, 1930, the gross production for the field was 113,427,000 barrels from 612 wells, on approximately 10,000 acres.

There have been 630 wells completed, 18 of which are dry holes. At the present time 564 wells are producing.

[1]Read by title before the Association at the New Orleans meeting, March 22, 1930. Manuscript received by the editor, March 10, 1930.

[2]Geologist, Southern Crude Oil Purchasing Company.

The writers wish here to express their appreciation to the various companies and individuals for information and samples made available. The description of well cuttings and the determining of limestone tops in the field are the work of L. C. Roberts, Jr., R. B. Cheney, and the writers.

History of Discovery

R. A. Westbrook and associates drilled the discovery well in the Hendrick field. This well is located in Sec. 42, Blk. B-5, Public School Land Survey.

This cable-tool well was commenced on February 25, 1926. Progress was slow due to the many water sands encountered, necessitating much under-reaming. The top of salt was encountered at 1,930 feet, or +794 feet, sea-level datum, making this well at that time the lowest on the top of salt of any well in the basin.

At 2,524 feet, about 250,000 cubic feet of gas and some oil were encountered, the oil filling up approximately 1,500 feet of hole. The formation at this depth was anhydrite and sand. The well was placed on the pump and after pumping 400 barrels of oil, pumped dry.

Drilling was resumed and more salt was encountered.

At 2,738 feet approximately 1,000,000 cubic feet of sulphur gas was encountered in a brown limestone; some heavy black oil was also encountered that was exhausted after bailing 8 hours. Other showings were encountered, and after deepening to 3,006 feet the well began flowing by heads at the rate of 120 barrels per day.

The Southern Crude Oil Purchasing Company, after purchasing the discovery well, deepened it to a total depth of 3,052 feet, increasing the production to 390 barrels per day.

Immediate development began and continued at a rapid rate until proration became effective, May 5, 1928, at which time 164 wells were producing a potential of 521,597 barrels per day from seventy-nine 40-acre units.

Location

The Hendrick field is in the central part of Winkler County, Texas.

The Texas and Pacific Railroad was the nearest railroad during the major development of the field, but later the Texas and Mexico Railroad was built from Monahans, Texas, on the Texas and Pacific Railroad, to Wink and Kermit, Texas. The present Hendrick field is 10 miles long and 4 miles wide, comprising approximately 10,000 acres (Fig. 1).

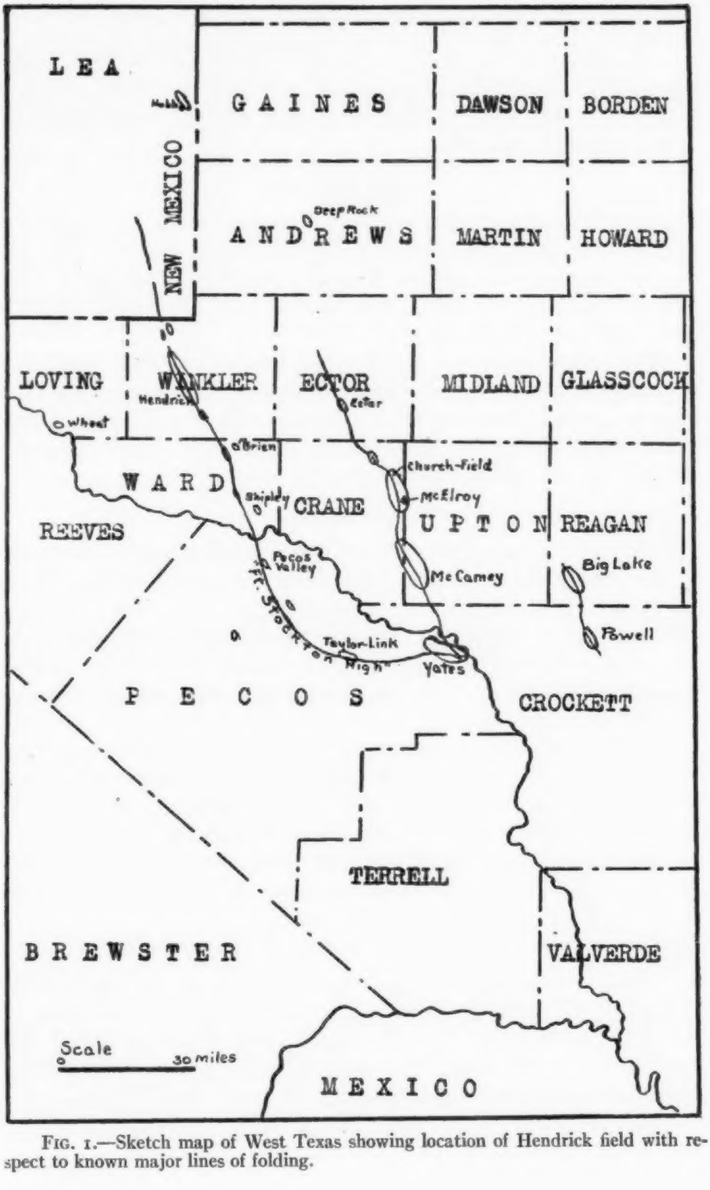


FIG. 1.—Sketch map of West Texas showing location of Hendrick field with respect to known major lines of folding.

Topography

Hendrick field lies in one of the most sandy areas of West Texas, the sand dunes forming a topographic "high" extending north and south through the field. The average elevation in the field is approximately 2,850 feet above sea-level.

Areal Geology

There are no well recognized formations exposed in the vicinity of the Hendrick field. The surface sand which forms a mantle over the area is probably disintegrated Basement sandstone, although a large part of it may be wind-blown sand derived from the Triassic which is found on the north and west.

The nearest outcrop to the Hendrick field is the Triassic sandstone which forms a southwest-facing escarpment extending southeastward from southeastern Lea County, New Mexico, into Ward County, Texas, near Quito station, on the Texas and Pacific Railroad. This escarpment is approximately 16 miles west of the field.

Subsurface Stratigraphy

Stratigraphic work in the West Texas Permian basin differs from that in other areas in that drillers' logs are of little value. Fossils are rare and even those found have such a great vertical range that they have been of no help in correlation. Constant stratigraphic units are rare, so that dependence for correlation must be placed upon comparative lithology determined by a careful examination of drill cuttings taken at close intervals.

Two systems, Triassic and Permian, are encountered in the wells in the Hendrick field. The study of the Triassic and upper Permian in this area has been handicapped by the lack of cuttings from these formations. With the exception of several wells drilled with standard tools close to the discovery well, practically all wells have been drilled with rotary equipment and cuttings from the upper formation have been of little value.

TRIASSIC

Below the surface sands and above the anhydrite of the Permian is a series of sandstones, sandy shales, and gravels, which, because of their stratigraphic position and lithologic character, are correlated with the Triassic of other areas. The character of the Triassic of West Texas has been thoroughly described by Adams.[1]

[1] J. E. Adams, "Triassic of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 1045-55.

The thickness of this formation, as approximately determined from drillers' logs and available samples, shows considerable variation throughout the field. The greatest thickness is attained on the extreme west flank, where as much as 1,500 feet is present, and the formation thins within a short distance toward the east, being about 600 feet thick on the east side of the fold (Fig. 2).

PERMIAN

The Permian section penetrated in wells in this area is generally divided into two parts, an upper Red-bed and evaporite series, and a lower dolomitic limestone.

RED-BED SERIES

The upper part of the Permian in this area is represented by several hundred feet of brick-red shales and sandy shales with varying amounts of gypsum. The unconformity between this section and the overlying Triassic is marked by irregularity in thickness of the Permian Red-beds and a few beds of gravel and coarse sands at the base of the Triassic.

EVAPORITE SERIES

In this area the evaporite series may be divided into two parts, an upper anhydrite-dolomitic limestone series and a lower anhydrite-salt series.

Anhydrite-dolomitic limestone series.—The base of the upper Permian red shales marks the top of this series, which ranges in thickness from about 250 feet on the west side of the Hendrick field to about 200 feet on the east side. Drill cuttings from wells on the west side of the field show 100 feet of anhydrite and gypsum, 50 feet of tan to light gray, porous, commonly oölitic, dolomitic limestone, 20 feet of dolomitic limestone and soft blue shale, and 70 feet of soft red and blue shales, with a few dolomitic limestone stringers. Because of the lithologic character and stratigraphic position of this formation, it is correlated with the Rustler of Richardson.[1]

The Rustler section grades to anhydrite, salt, and red shales toward the east, and in eastern Winkler County there is no dolomitic limestone in this section.

Anhydrite-salt series.—These beds range in thickness from 700 feet on the extreme west side of the producing area to 1,500 feet on the east flank (Fig. 2). There are two distinct salt zones present in this area, an

[1] G. B. Richardson, "Report of a Reconnaissance in Trans-Pecos Texas, North of the T. & P. Ry." *Texas Univ. Min. Survey Bull. 9* (1904), pp. 43-45.

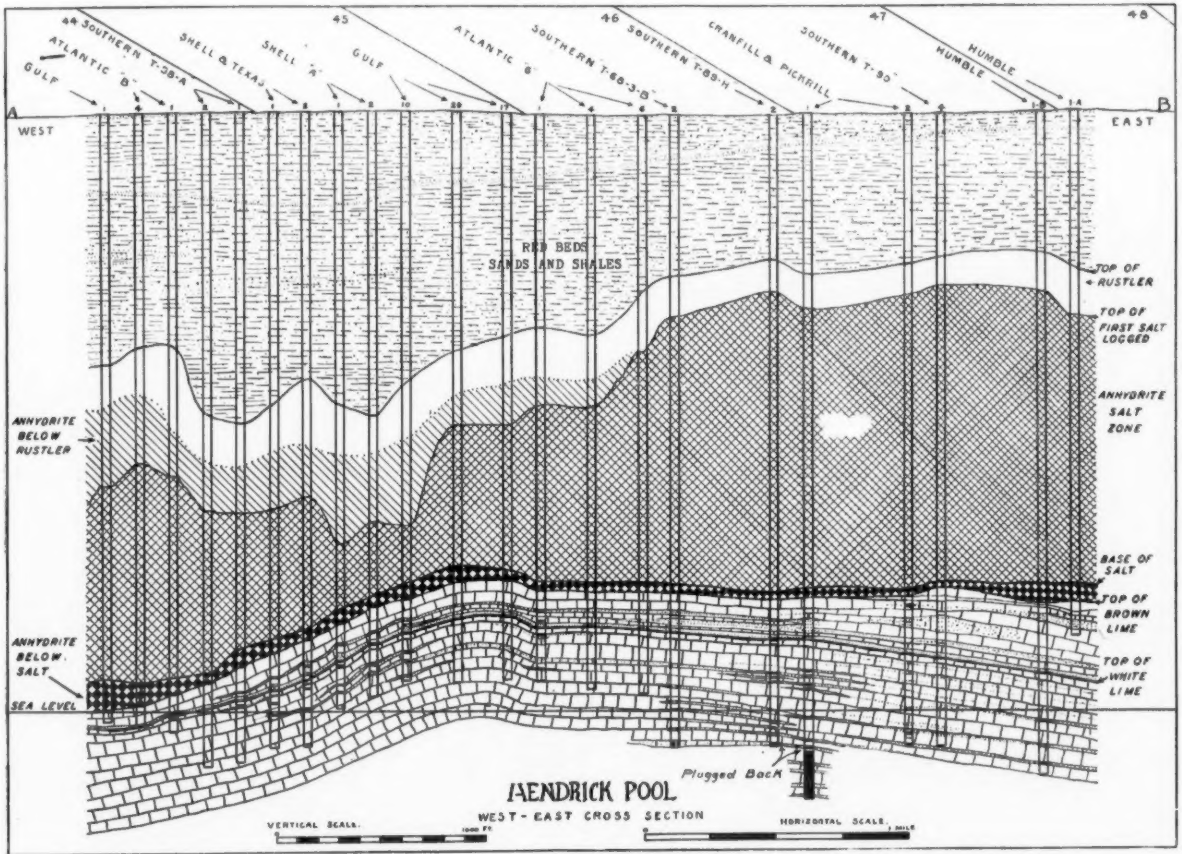


FIG. 2.—West-east cross section through Hendrick field, based on logs compiled from drillers' logs and well cuttings.

upper salt zone of variable thickness and extent, and a lower persistent zone.

The upper salt generally occurs immediately below the Rustler section. In many places it is found in contact with the dolomitic limestone of the Rustler, although in some areas it is separated from this limestone member by a variable zone of anhydrite and red and blue sandy shales. In the Gulf Production Company's Hendrick No. 1, located in the northwest corner of Sec. 24, Blk. B-5 (this being a direct east offset to the discovery well), this salt series has a thickness of 610 feet, although in the Southern Crude Oil Purchasing Company's Hendrick 67-1-A-1, the discovery well, this upper salt zone is 490 feet thick. The direct west offset to this well, the Independent Oil and Gas Company's Hendrick No. 1, did not encounter any true salt in this zone. Samples, however, show much salt filling fractures and cavities in the anhydrite section. That this well was drilled through a fractured zone is shown by the many anhydrite fragments encountered, ranging from 2 or 3 inches to 6 inches in diameter. Figure 7 shows fracturing in the anhydrite section on the west side of the field. Little is known of that area between the most westerly producers and the Humble Oil and Refining Company's Hendrick No. 1, in Sec. 36, Blk. 26. The upper salt series was found also in this test, although the zone is only 160 feet thick. Eastward from the Gulf Production Company's Hendrick No. 1, this salt zone gradually thickens, and in the Southern Crude Oil Purchasing Company's T-90-1 it has attained a thickness of more than 900 feet. The top of the salt in this well was encountered slightly above 1,905 feet, sea-level datum, this being the highest top-of-salt point in the area.

Lower salt zone.—This zone is of fairly uniform thickness throughout the producing area, and is approximately 40 feet thick.

Anhydrite series.—Anhydrite occurs throughout the upper salt series. One zone about 200 feet in thickness separates the upper and lower salt. From the base of the last salt to the top of the "Brown lime" is a 50-foot bed of hard, finely crystalline anhydrite, which is persistent throughout the area (Fig. 2).

The absence of salt on the extreme west flank of the producing area can be best attributed to solution and subsequent slumping. There is much evidence that fracturing accompanied movements at the end of Rustler time, these fractures giving access to underground waters and resulting in solution of the salt. To explain the absence of salt in some areas of the Hendrick field by gradation does not seem plausible, when it is considered that as much as 500 feet of salt encountered in one well

is missing in an offset well, as is the situation in the discovery well and its west offset, the Independent Oil and Gas Company's Hendrick No. 1. Great differences in the salt section are also encountered in wells having the same elevation on structure, such as the Richardson Sealy No. 1, in Sec. 50, Blk. F, and the Wentz Oil Company's Morton No. 1, in Sec. 27, Blk. B-12. These wells are less than ½ mile apart, yet the Wentz well encountered a total salt section of 915 feet as compared with 490 feet in the Richardson well.

The deep syncline on the Rustler (Fig. 2) is probably due to two factors: (1) slumping due to solution of salt, and (2) structural movements during Triassic time.

"*Big lime.*"—Beneath the anhydrite series in this part of the basin is a group of beds commonly referred to as the "Big lime." In the Hendrick field the "Big lime" is divided by most geologists into a thin, upper member known as the "Brown lime," and a lower member of undetermined thickness known as the "White lime." Sample examination shows that there is a fourfold division of the "Big lime" series in this area, or, more concisely, two main divisions, the upper of which is divided into three phases.

The upper main division, or "Brown lime" of common usage, ranges in thickness from 180 feet on the west side of the field to 350 feet in the Humble Oil and Refining Company's Walton No. 1-B, in Sec. 47, Blk. 26, this well being on the east flank of the structure. The highest member of this main division is a non-sandy phase of dolomitic limestone of variable thickness, and characteristically browned with oil. This member thickens eastward and grades into a sandy phase. Gradation of limestone to anhydrite and vice versa is common throughout this member, and in some places the gradation to anhydrite is complete. From the crest of the structure to the west limit of production this member is persistent in thickness and composition. Change in section, together with thickening and thinning, is common in the saddles and on the east flank. The middle division of the "Brown lime" section is a sandy phase characterized by a profusion of large, well sorted and rounded frosted quartz grains, with an average diameter of 0.7 millimeter. Quartz is the most plentiful mineral, constituting about 95 per cent of the grains. Pyrite, occurring both as a cement and as fine crystals, is common. Acid plagioclase feldspars and orthoclase, showing varying degrees of alteration, and microcline are present. Zircon, tourmaline, and pyrite are the common accessory minerals.

The lower sandy phase of the "Brown lime" section is that member occurring in contact with the "White lime." It is made up of fine sandstones interbedded with brown and gray dolomitic limestone. Unlike the middle sandy phase, the quartz grains in this member are uniform throughout, and the large frosted quartz grains are not present. Drill cuttings from various wells in the area show these frosted quartz grains to be present in this lower section. Inasmuch as the top of the "Brown lime" is the common casing point in this area, it must be considered that lower samples are subject to contamination. A careful examination of the cores from the Southern Crude Oil Purchasing Company's No. 88-M-15, in Sec. 33, Blk. 26, shows a definite break between these two sandy members, the lower member containing no frosted quartz grains. Microcline is the common feldspar, and occurs in greater profusion than in the middle sandy phase. Plagioclase and orthoclase occur in small amounts. Amphiboles and pyroxenes make up a small percentage of the grains.

The lower main division, or "White lime," is the main producing section in the Hendrick field. Most of the wells show a bentonite bed which is a fairly definite marker occurring 40-50 feet below the top of the "White lime." Other bentonite zones have been encountered below this point, but these have been of little value for correlation work, inasmuch as bentonite has a great tendency to cave upon absorption of water, so that, unless the succeeding beds differ from the first, these new horizons can not be determined from cuttings.

The "White lime" series consists of light gray, white, and flesh-colored dolomitic limestones with some fine-grained gray sandstones. In some parts of this area the upper part of the "White lime" section is made up entirely of sandy limestone. This change in the "White lime" section occurs on the extreme west flank of the structure, in the deep saddle at the south end, and on the east side. These sandstone members with interbedded limestone are lenticular, and abrupt changes of limestone to sandstone in offset wells are common. Beds of dark red shales and sandy shales ranging in thickness from 3 or 4 feet to 20 feet are found in these sandy limestone areas.

Porosity occurs in the form of irregular solution cavities as large as 2 inches in diameter. Some of these cavities are filled with anhydrite. Pyrite occurring in minute crystals lines the cavities and shows the purely secondary nature of the anhydrite (Fig. 6). Solution cavities lined with calcite crystals are commonly found in the pay horizons. Calcite occurs plentifully in the "White lime" section on the west flank of the structure and may be due to fracturing. Drill cuttings from the pay

horizon in the discovery well and the offset wells show as much as 50 per cent free calcite, some of the crystals being ½ inch in length. In the granular phases there are very minute interstitial voids which also constitute porosity. An oölitic zone was encountered by the discovery well at a depth of 3,036 feet. This zone has been reported in several other wells, but the occurrence is localized.

A detailed study of the drill cuttings reveals few signs of fossils, but cores show that some parts of the rock are distinctly fossiliferous and that other parts are barren. Algae, appearing mostly as more or less rounded balls and showing concentric structure, have been found in cuttings from several wells (Fig. 9).

A few gastropods have been found in cores, but these have not been identified.

Stratigraphic Occurrence of Oil and Gas

Oil and gas are produced from the "White lime" section of the "Big lime" in this area, and in some parts of the field from the "Brown lime" section immediately above it. With the exception of the extreme west flank of the producing area, the first commercially productive oil zone is encountered 150-250 feet below the top of the "White lime." On the top of the fold this horizon is gas-bearing and here the first oil "pay" is encountered approximately 300 feet in the "White lime" section. East of the axis of the fold the first oil "pay" is even more variable, occurring 400-450 feet below the top of the "White lime." Other oil-bearing porous horizons are encountered on the west flank at intervals of approximately 175 and 275 feet from the top of the "White lime." These porous horizons are fairly uniform from the west edge to the crest of the structure, but they are not correlative with those occurring on the east flank, where they vary considerably throughout the section, many being only local porous lenses.

The occurrence of commercially productive oil horizons in the "Brown lime" member of the "Big lime" section on the extreme west flank of the structure is attributed to migration from the regular "pays" through fractures. Oil and some gas also occur in this part of the field in the sandy limestone section at the base of the "Brown lime" member. This occurrence has also been noticed in the south end of the field in Secs. 3 and 10, Blk. B-12. In addition to this "pay," wells drilled in these two areas encounter the regular "White-lime pay."

Gas is found in varying amounts throughout the field. Like the oil-producing horizons, these gas zones are not uniform, except on the

west flank, where the most persistent zone is in the sandy limestone member at the base of the "Brown lime." During the early development of the field, gas in large quantities was encountered on the top of the structure in the first three pay zones correlative with those found on the west flank. The Texon Oil and Land Company's Hendrick No. 1-A, located in the southwest corner of the SE. 1/4 of Sec. 34, Blk. B-5, was the first large gasser drilled in this area. This well encountered 5,500,000 cubic feet of gas in the lower "Brown lime" section and the amount increased in the "White lime" at 2,545 feet and 2,500 feet. Some gas and a small showing of oil were encountered from 2,633 to 2,648 feet, this being the first oil-producing horizon in the structurally lower wells. Gas increases were found at 2,746 and 2,790 feet, and at 2,811 feet the well gauged 50,000,000 cubic feet of gas. Oil was encountered at 2,898 feet with increases to 2,935 feet, from which depth the well began producing 4,068 barrels per day. This production increased to a maximum of 4,300 barrels.

The Atlantic Oil Producing Company's Hendrick No. 1-C, located in the southwest corner of Sec. 40, Blk. B-5, encountered gas in the Texon "pay" at 2,787 feet, and when drilled to 2,978 feet it gauged 60,000,000 cubic feet of gas with a slight spray of oil. After producing gas for 4 months it began making 200 barrels of fluid per hour, 18 per cent water. All of the early wells drilled in this gas area have a similar history.

On the east side of the area, large gas wells are encountered in the "Brown-lime" section. The Amerada Petroleum Corporation's Walton No. 1, in the southwest corner of the N. 1/2 of Sec. 48, Blk. 26, encountered 50,000,000 cubic feet of gas at 2,410 feet.

Deposition of Permian

The "White-lime" member of the "Big-lime" series is shown by its fossil content to be a deposit of normal marine waters. The overlying anhydrite-salt series is a desiccated sea deposit which lies conformably upon the shallow-water "Brown-lime" phase of the "Big-lime" series. Open sea conditions existed during "White-lime" time with shallowing toward its close and during the deposition of the "Brown lime." This shallowing of the sea resulted in a barrier which partly cut off the West Texas basin from the main ocean. Desiccation followed with accompanying deposition of the evaporite series.

The presence of fine sandstones and red and blue sandy shales in the upper part of the "White-lime" section shows that this area was being supplied by detrital material from a constant source. This deposi-

tion continued throughout "Brown-lime" time. Conditions were not static and lenses of sandstones and dolomitic limestones were deposited locally in the "Brown-lime" section. That this condition existed during the closing period of "White-lime" deposition is shown by the occurrence of many sandstone lenses and red sandy shales in the upper "White-lime" section.

Development of Structure

Two distinct periods of deformation are recognized in the development of the structural features in this area. Movements near the close of "White-lime" time resulted in the Winkler County arch, which remained a positive segment during "Brown lime" deposition. Figure 3 is a west-east cross section through the Hendrick field showing overlap of the "Brown lime" on the "White-lime" barrier. Development of porosity was probably contemporaneous with "Brown-lime" deposition, as the top of the structure was exposed to the action of circulating ground waters. Movements at the end of Permian time and during the Triassic resulted in the shifting of the axis of the fold east to its present position. This movement accounts for the presence of the "Brown-lime" and sand section on the west flank of the structure (Fig. 3). Since this section shows a decided thinning from the present axis westward to the Humble Oil and Refining Company's Hendrick No. 1, in Sec. 36, Blk. 26, which did not encounter any "Brown lime," it is very probable that this well is located close to the ancient axis.

Subsurface structure maps.—The accompanying map (Fig. 4) depicts, by use of contours drawn on the top of the "Brown lime" as datum, the probable subsurface structure of the Hendrick field. This contour map indicates the presence of a long anticline, having a slightly northwest-southeast-trending axis. The highest area of uplift occurs in the southeast part of Sec. 45, Blk. 26, and the northeast part of Sec. 41, Blk. B-5, these areas being above the 650-foot contour. Many irregularities such as basins and local "highs" near individual wells are due largely to errors in measurement resulting from crooked holes (Fig. 8).

The west flank of this Hendrick fold is marked by a steep inclination of the "Brown lime," especially below the 600-foot structural contour. The structural interpretation shown in Figure 4 indicates a dip of approximately 600 feet to the mile along this flank. On the east flank the dip varies considerably and shows a decided flattening on the east-central part of the structure in Sec. 47, Blk. 26.

Figure 5 is a structural contour map of the Hendrick field drawn on the top of the "White lime" as datum. This interpretation differs from

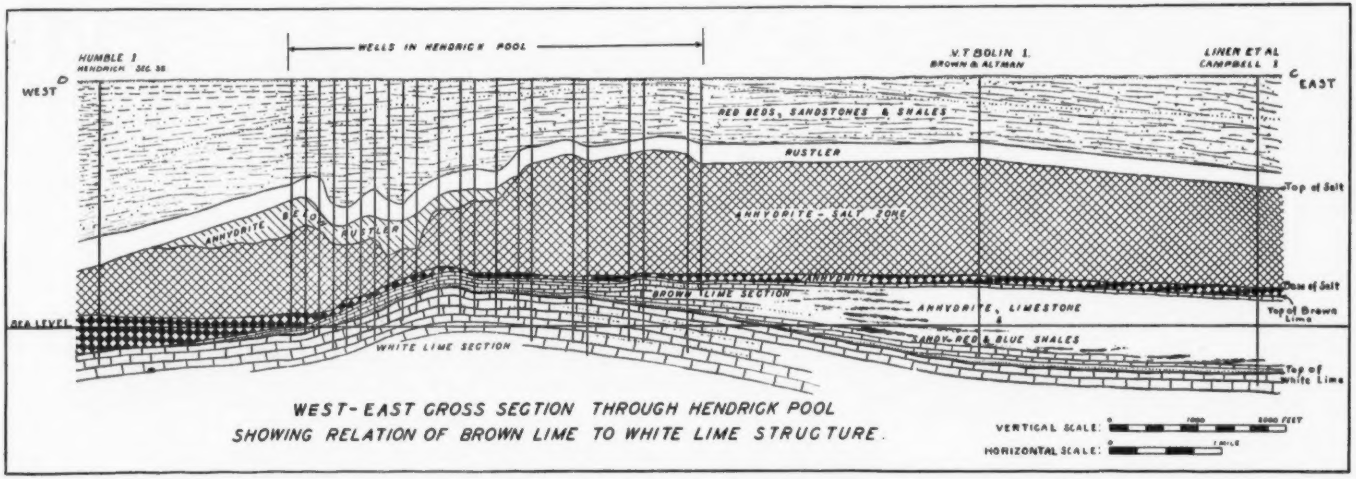


FIG. 3.—West-east cross section through Hendrick field, showing the relation of "Brown-lime" to "White-lime" structure.

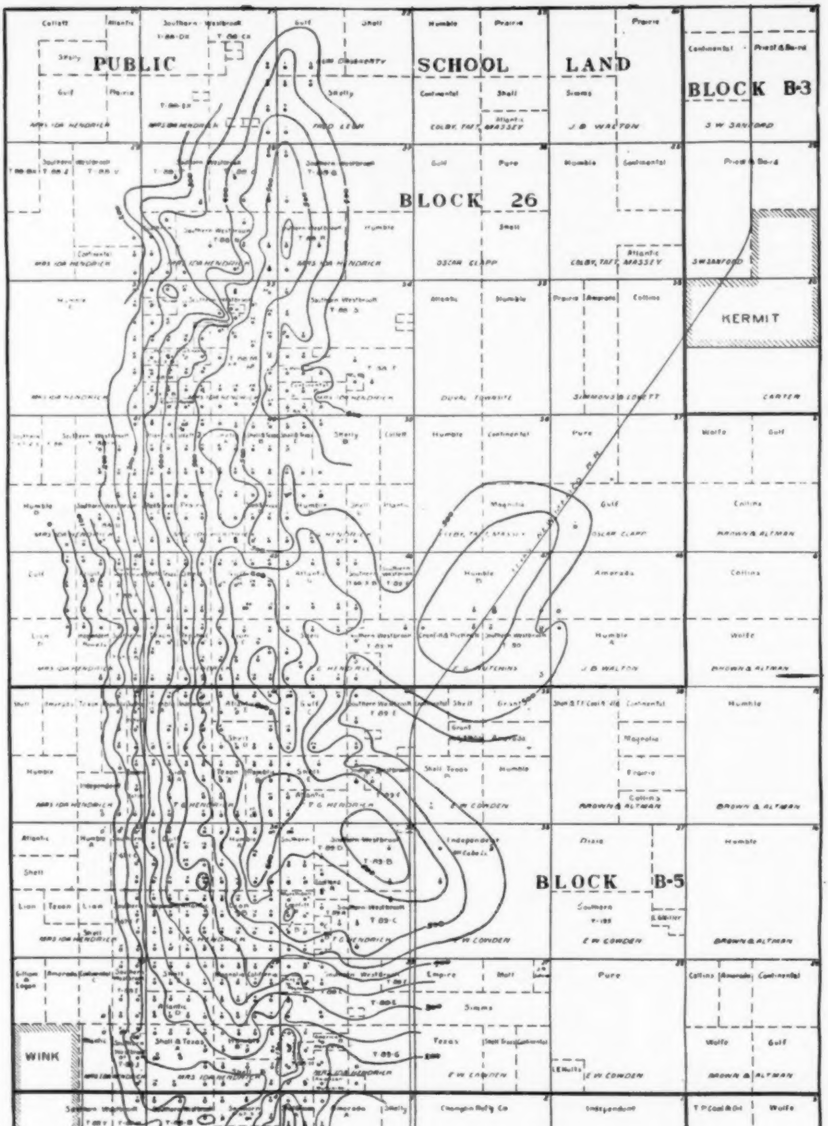


FIG. 4.—Subsurface structure of Hendrick field contoured on top of the "Brown lime." Contour interval, 50 feet.

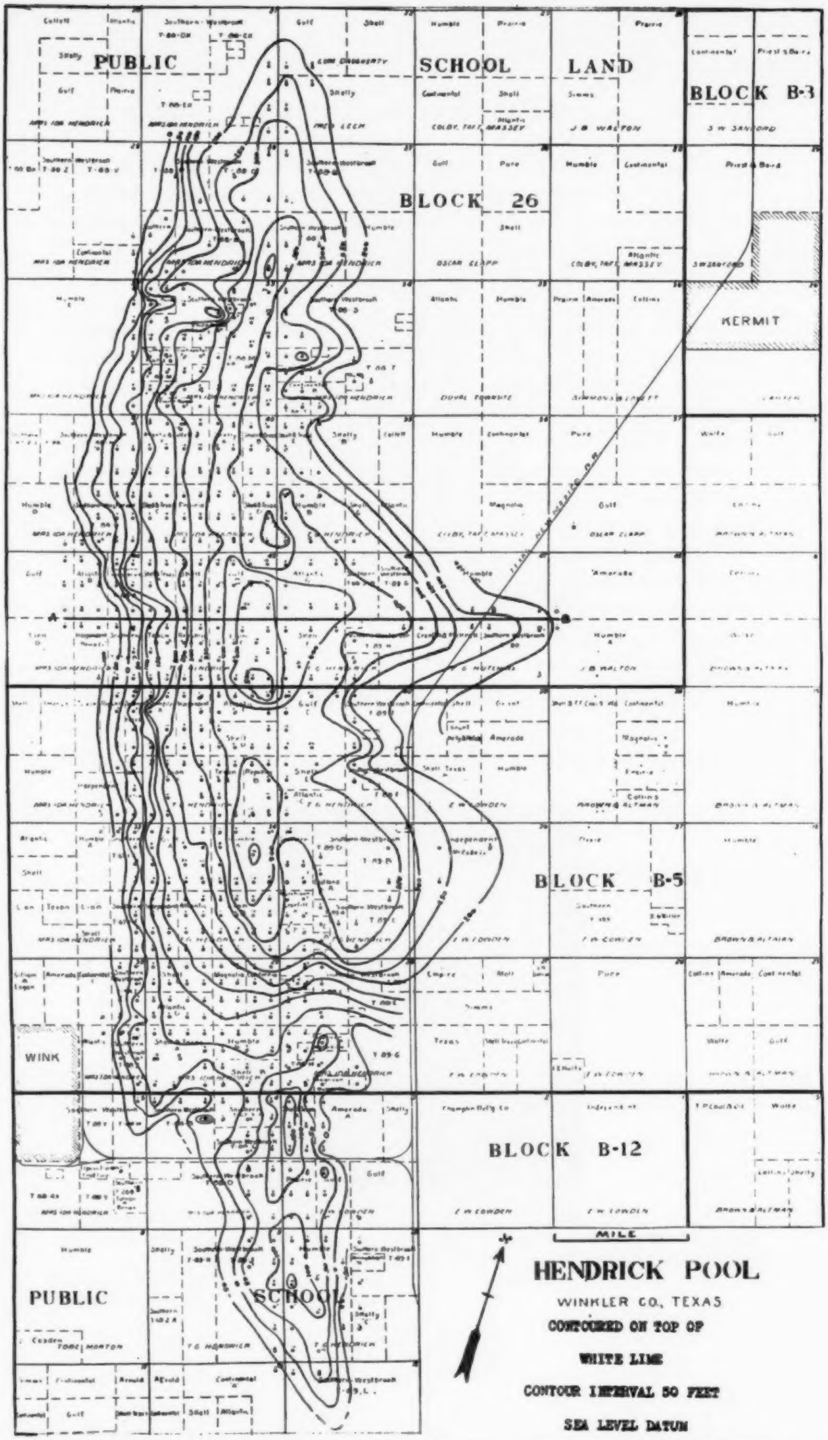


FIG. 5.—Subsurface structure of Hendrick field contoured on top of the "White lime." Contour interval, 50 feet.

that obtained by using the top of the "Brown lime" in that minor irregularities are not as many and the east dip of the fold is accentuated. Several small closed structures, notably the one in Sec. 47, Blk. 26, and that in Sec. 35, Blk. B-5, are not reflected on the "White lime."

Accumulation of Oil and Gas

Source of oil and gas.—There has been much discussion among geologists as to the source of the oil and gas that is being produced from the dolomitic limestones of West Texas. Some maintain that the oil has migrated upward from the black carbonaceous shales of the Pennsylvanian. Others incline to the belief that sufficient minute organic life occurred in the Permian seas of West Texas during lime deposition and that the source of the oil is in the dolomitic limestones. The writers are inclined to favor the latter theory.

Relation of accumulation to structure.—In the Hendrick field, the most prolific production is found on the crest and west flank of the structure. This condition exists because the greatest porosity is present in these areas.

Water

On June 27, 1927, the Independent Oil and Gas Company's Hendrick No. 1, Sec. 42, Blk. B-5 was drilled into sulphur water at a total depth of 3,092 feet, or −268 feet, sea-level datum. Several other wells were drilled

Fig. 6.—Photograph of 3-inch limestone core from Southern Crude Oil Purchasing Company's Hendrick T-67-3-B-1, Sec. 33, Blk. 26, at 2,733 feet. This core shows former cavities filled with pyrite and anhydrite.

FIG. 7.—Photograph of anhydrite 3-inch core from Southern Crude Oil Purchasing Company's Hendrick T-88-P-1, Sec. 28, Blk. 26. This core shows fracturing in the anhydrite section.

FIG. 8.—Photograph of 3-inch core from Southern Crude Oil Purchasing Company's T-88-N-3, Sec. 28, Blk. 26, showing 40° dip on sandstone. The hole at this depth, 2,350 feet, was 32° off vertical.

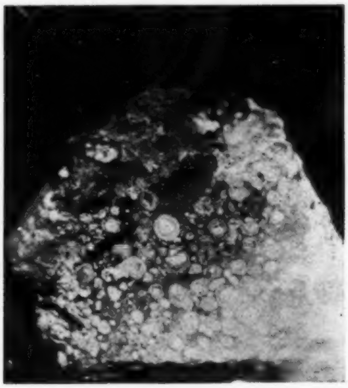


FIG. 9.—Photograph of core showing algae ¼ inch in diameter. Magnification ¾ diameter.

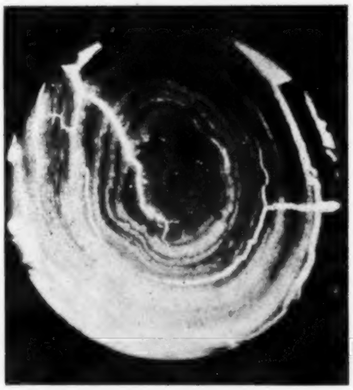


Fig. 10.—Micro-photograph of alga from Capitan outcrop, New Mexico. Magnification 6 diameters.

into sulphur water and all encountered this bottom water at approximately the same depth below sea-level.

On December 13, 1927, the Magnolia Petroleum Company's Hendrick No. 2, Sec. 29, Blk. B-5, began showing sulphur water while drilling at 2,955 feet, or −149 feet, sea-level datum. Within 2 weeks the 3 offset wells began showing sulphur water, and 3 months later the production of 75 wells varied from ½ per cent to 98 per cent water.

Most of these first wells were located in three distinct zones in Secs. 29, 34, and 41, Blk. B-5, and Sec. 4, Blk. B-12. As drilling progressed, water began showing in all of the wells in the Hendrick field. At present all of the wells in the field are making large quantities of water.

Water samples were obtained from many wells in the field, and analyses were made by the Fort Worth Laboratories, according to the Chase Palmer method.[1]

The analyses are plotted graphically, according to the percentages of reacting values of the alkaline, alkaline earth, chloride, sulphate, and carbonate radicals on a pentagonal diagram (Fig. 11).

This method permits a direct comparison of all the analyses taken in the field.

Diagrams shown in Figure 12 are believed to be characteristic of certain type waters found in the field.

The water is sulphurous in character and is thought to be coming up through fractures and fissures in the limestone. Wells on the apex of the structure are making more water than edge wells.

Drilling and Production Methods

Most of the companies in the Hendrick field use rotary equipment to drill to the top of the "Brown lime" and then drill in with standard tools. In areas where gas pressure was exceptionally high, a few of the companies completed the wells with rotaries. A well is commenced with a large bit and the hole drilled to a depth of 300-900 feet, where 15½- or 12½-inch casing is set and cemented to exclude surface water. Drilling is continued with rotary tools to the top of the "Brown lime" or a few feet into the lime, where 8⅝ or 8¼-inch casing is set and cemented with 500-600 sacks of cement. At this point most of the companies standardize and drill in with standard tools. In a few of the wells 6⅝-inch casing has been set in the "White lime" below the gas. In the Southern Crude Oil Purchasing Company's 67-3-B-1, Sec. 33, Blk. 26, 5³⁄₁₆-inch casing

[1]Chase Palmer, "The Geochemical Interpretation of Water Analyses," *U. S. Geol. Survey Bull. 479.*

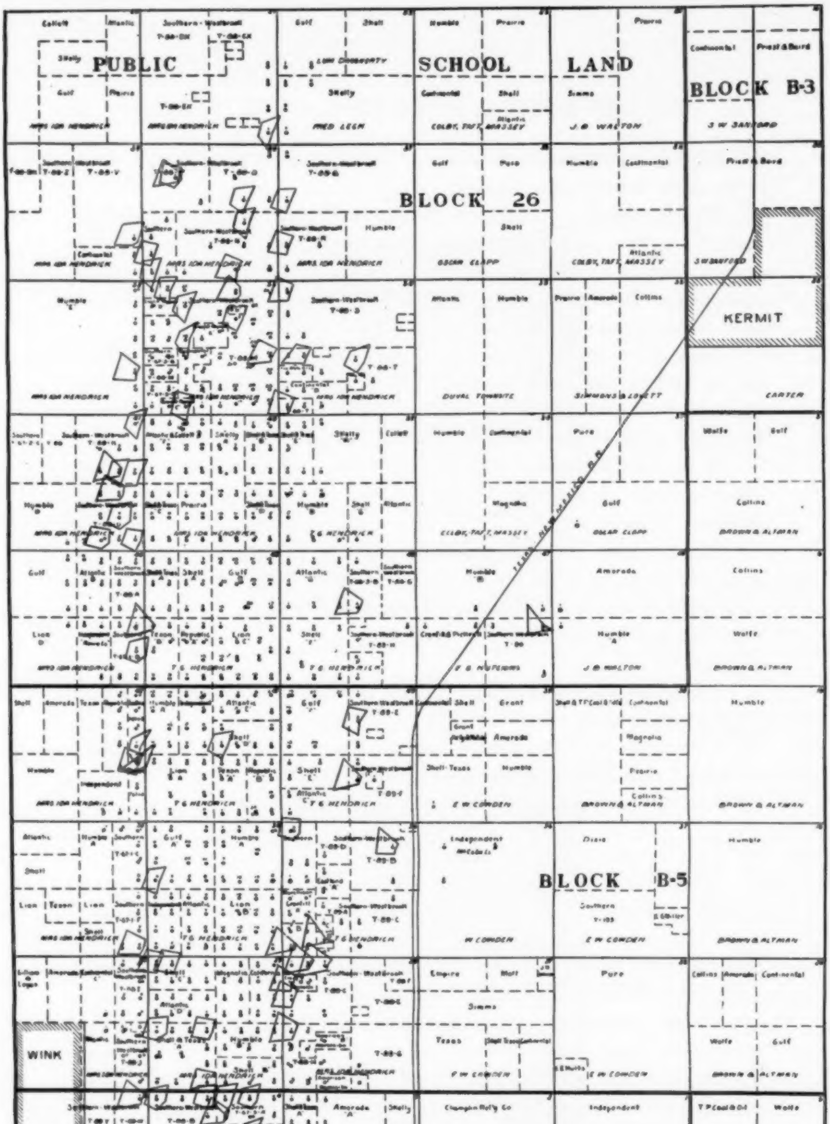


FIG. 11.—Graphic representation of water analyses.

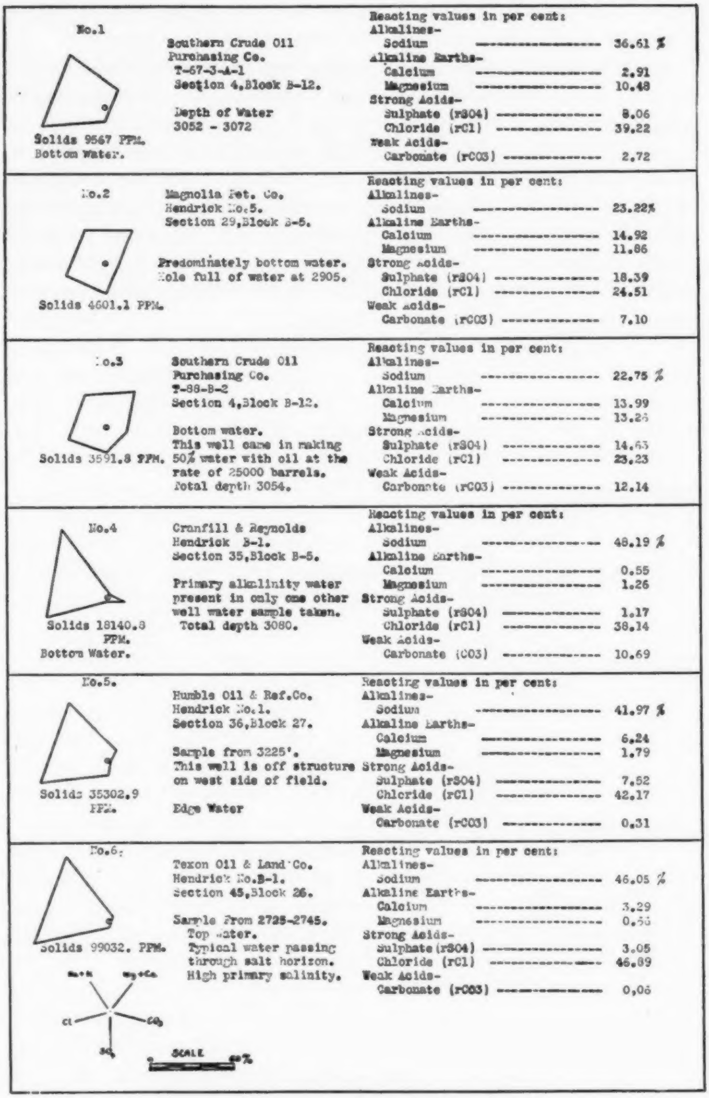


FIG. 12.—Diagrams showing typical water analyses.

has been set and cemented at 3,960 feet below all present known "pays." This well is standing cemented at a total depth of 3,962 feet.

In the Hendrick field wells are completed, flowing as much as 15,000 barrels per day, but decline is ordinarily rapid and the wells soon make a large percentage of sulphur water with the oil. Most of the wells are pinched in to reduce the water, and in a comparatively short time tubing is placed in the well and the well put on the beam. When it is necessary to treat the oil, the companies have installed electrical, mechanical, and chemical methods. The water and oil are easily separated and a few companies have built large earthen tanks to take care of wells making large quantities of water. Some of the wells are making as much as 20,000 barrels of water to 50 barrels of oil a day.

GEOLOGICAL NOTES

OIL WELL IN AUSTRALIA

After a search during a period of more than 16 years, the South Australian Oil Wells Company has succeeded in discovering crude oil in Australia. Although the well is a small one, with a production capacity of only approximately 10 barrels of oil a day, it proves that, contrary to the opinion of some local and visiting geologists, petroleum does exist in Australia.

Location.—The field is situated in the district of Gipsland, 200 miles east of Melbourne, the capital of Australia, and a mile from the seaside town, Lakes Entrance. The drilling site is 1 mile north of the coast. It is reached by steamer from Melbourne, or by train to Bairnsdale 23 miles away and thence by steamer or by car to Lakes Entrance.

Topography.—The field is in a flat and low-lying plain for a mile inland from the shore; thence there is a gradual rise to rolling country with a maximum elevation of 200 feet above sea-level, intersected by small, steep water courses draining to the coast. The region has a generally mild climate, with a very mild winter climate. The rainfall is 12-14 inches per year.

Geology.—The country from Sale to Orbost along the sea-coast, comprising an area more than 100 miles long (east-west) and 20-40 miles wide, is covered with light-colored, soft sands, gravels, and marls. Their maximum thickness is 100 feet. They overlie unconformably the Miocene, which is 1,100-1,300 feet thick and which lies on the granite. The hole passes through the following sediments: 100 feet of sand and gravel; 1,000 feet of white-to-gray fossiliferous marls; dark, sandy clays with several bands of hard limestone as much as 12 inches thick; a hard glauconite bed; and the oil-bearing sand, dark green because of its glauconite. The oil sand is 38 feet thick, with a few ½-inch bands of hard glauconite. There is gas with the oil, but not sufficient to make a flowing well.

Strata.—The strata have a general dip southward of approximately 130 feet per mile, with gentle monoclinal folding. This seems to be an edge well, and the main concentration will probably be found at the north.

Crude oil.—The crude oil is dark green, with strong petrol-kerosene odor; it contains about 0.5 per cent gasoline, 24 per cent heavy kerosene,

18 per cent light lubricating oil, 12 per cent medium lubricating oil, 27 per cent heavy lubricating oil, and 16 per cent bitumen. The average gravity is about 20° Bé.; the calorific value, 18,360 B.T.U.

Drilling.—Oil occurs at a depth of 1,250 feet. Drilling was done with a portable percussion plant, during a period of two months. Rotary plants are not suitable, as water is very scarce, and all water for boiler feed has to be carried by truck to the bore. This bore is now being put on the pump, and the rig moved to a new location 200 yards north. Another well is being drilled 2 miles west by the same company. This company owns 4 square miles in the center of this field.

The discovery of this well marks an important point in the history of Australia, because it shows that crude oil does exist. The writer is sure that after more development work crude oil will be found in commercial quantities.

H. S. Lyne

Lakes Entrance, Victoria, Australia
May 7, 1930

DISCUSSION

LOWER PALEOZOIC UNCONFORMITIES

I wish to take exception to this statement by Mr. S. W. Lowman.[1]

> One important angular unconformity is found at Big Lake that has not been noticed in Oklahoma. This occurs between the Sylvan shale (Richmond) and subjacent Ordovician strata of Chazy age.

Some of the angular unconformities that occur in Oklahoma in the interval mentioned by Mr. Lowman are here listed.

Post-Fernvale-pre-Sylvan (intra-Richmond)
Post-Viola-pre-Fernvale (post-Cincinnatian-pre-Richmond)
Post-Bromide-pre-Viola (post-Black River-pre-Trenton?—Cincinnatian)
Post-Tulip Creek-pre-Bromide (post-Chazy-pre-Black River)

These angular unconformities are recognized by all Mid-Continent stratigraphers familiar with the lower Paleozoic sediments.

FANNY CARTER EDSON

TULSA, OKLAHOMA
June 17, 1930

[1] S. W. Lowman, "Pre-Pennsylvanian Stratigraphy of Big Lake Oil Field, Reagan County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), p. 799.

RESEARCH NOTES

A. A. P. G. RESEARCH COMMITTEE

(Members' terms expire immediately after annual Association meetings of the years shown,

ALEX W. McCOY (1932), *chairman*, 919 East Grand Avenue, Ponca City, Okla.
DONALD C. BARTON (1933), *vice-chairman*, Petroleum Bldg., Houston, Tex.

1931:
K. C. HEALD, 1161 Frick Bldg. Annex, Pittsburgh, Pa.
F. H. LAHEE, Box 953, Dallas, Tex.
R. C. MOORE, Univ. of Kansas, Lawrence, Kan.
F. B. PLUMMER, Bur. Econ. Geology, Austin, Tex.
M. K. READ, 1519 Linda Rosa, Los Angeles, Calif.

1932:
C. R. FETTKE, 1118 Wightman, Pittsburgh, Pa.
A. I. LEVORSEN, Box 1830, Tulsa, Okla.
SIDNEY POWERS, Box 2022, Tulsa, Okla.
R. D. REED, 1110 Glendon Way, Alhambra, Calif.
L. C. SNIDER, 60 Wall Street, New York, N. Y.
W. C. SPOONER, Box 1195, Shreveport, La.
W. T. THOM, JR., Princeton Univ., Princeton, N. J.
F. M. VAN TUYL, School of Mines, Golden, Colo.
W. E. WRATHER, 4300 Overhill Dr., Dallas, Tex.

The purpose of the research committee is the advancement of research within the field of petroleum geology. If members working actively in research on particular problems care to register with the research committee, the committee will be glad to aid them in any way it can and put them in touch with other men who are, or have been, working on similar or allied problems and can perhaps effect some integration of the research work of the Association. If the younger, or older, members of the Association, who are doing or preparing research for publication, will come to any member of the committee, he will be very glad to offer whatever advice, counsel, or criticism he can in regard to the research, its prosecution, or its preparation for formal presentation. The committee would be glad to have members formulate and present to it suggestions in regard to research problems and programs.

COÖPERATIVE CROSS SECTIONS

One of the activities of the stratigraphic research project of the research committee, which is under the direction of R. C. Moore, is the preparation of a series of stratigraphic cross sections, showing the subsurface formations of the Mid-Continent fields. The cross sections are being prepared through the coöperation of the various oil companies and geologists working in this area. Each coöperating company or geologist prepares one cross section and in return is entitled to purchase prints of the cross sections prepared by other contributing companies or geologists. The cross sections connect the subsurface formations with the surface formations wherever possible, contain the best available subsurface information, and are as nearly accurate as it is possible to make them. Each cross section is made to a standard scale, with standard lettering and drafting and standard arrangement of logs, to the end that all completed cross sections may be uniform in general appearance. At present forty-two

cross sections are being made in Oklahoma, and thirty cross sections are being made in Kansas, by as many companies and geologists. The directions of the sections are either north and south or east and west and the result will be a network of cross sections covering the areas in these two states where subsurface information is available. Each cross section is copyrighted in the name of The American Association of Petroleum Geologists, and it is hoped that later, when sections are made in other parts of the Mid-Continent, the entire set — possibly consisting of one hundred and fifty or more sections — can be published by the Association in one volume.

A great mass of accurate information is contained in these sections, both for commercial and for scientific use. They are a very important aid in studies of sedimentation, geologic history, and correlation, and should have many applications in fundamental studies on the origin and accumulation of oil. Investigators of geological problems in the Mid-Continent will find in these sections much accurate material on which to base their conclusions, and it is hoped that as years pass they will form a background of facts increasingly useful to workers on the geology of petroleum.

A. I. LEVORSEN
Chairman, cross-section committee

TULSA, OKLAHOMA
June, 1930

RESEARCH COMMITTEE MEETING, MAY 23, 1930

The research committee met at Tulsa, Oklahoma, May 23 and 24, 1930. Members present were F. H. Lahee, Sidney Powers, R. C. Moore, L. C. Snider, A. I. Levorsen, and Alex W. McCoy.

A project on "A Study of Sedimentation of Sandstone Deposits in Pennsylvanian Formations," submitted by F. B. Plummer, requesting a grant of $600.00 from the Research Fund, was reconsidered. This is a plan to map the outcrop and study the lithology and mode of deposition of typical Pennsylvanian sandstones throughout their surface and subsurface extent.

A project on "A Study of the Regional Structure of the Dakota Sandstone in the Northern Plains Region," submitted by W. T. Thom, Jr., requesting a grant of $600.00 to cover half the total expense, the other half to be paid by Princeton University, was reconsidered.

The committee decided that these projects were too local in nature to be supported by the research committee, which should confine its work and financing to more general problems.

The committee discussed the research program for the year and outlined a plan to secure articles on subjects suitable for publication in 1931 as Volume III of *Structure of Typical American Oil Fields*. Subjects included in such a program are: Origin of Oil; Migration and Accumulation; Structural Development; Importance of Unconformities in Oil Accumulation; Analysis of Information on Carbon Radio; Porosity, Cementation, and Compaction; Variation of Oil Gravities; Petroliferous Provinces; and Oil-Field Waters.

The committee met with the research committee of the National Research Council to consider the research program of the American Petroleum Institute on Occurrence and Recovery. The Association committee members indorsed David White's project No. 3, "Studies of Source Beds in the Micro-Furnace," and W. V. Howard's project, No. 23, "Limestones and Dolomites as Reservoir Rocks."

REVIEWS AND NEW PUBLICATIONS

"Communication sur l'application pratique de la théorie paléogéographique des gisements pétrolifères." By STANISLAS ZUBER. IIe Congrès International de Forage (Paris, September, 1929). 6 pp. Printers, Société Anonyme de l'Imprimerie Théolièr, 12 Rue Gérentet, Saint Etienne, France.

Discovery of oil deposits in Albania, in which migration of the oil is evidently out of the question, leads the author to state his belief that oil has not migrated any appreciable distance. The reviewer thinks that the widespread anticlinal accumulation of oil alone proves that in many places oil must have migrated considerable distances. The problem to-day is, which oil deposits have not migrated, and which have, and how far? The author further states his belief that oil is formed from plants only. He calls attention to the importance of salt water in the process of oil formation. The importance of paleogeographic studies in connection with petroleum geology is stressed. There is much to be done in this field, and it is to be hoped that this paper will stimulate work on paleogeographic problems of present and prospective oil fields.

EDWARD BLOESCH

TULSA, OKLAHOMA
May 14, 1930

Oil Fields in the United States, by WALTER A. VER WIEBE (McGraw-Hill Book Company, Inc., New York, 1930). 620 pp., 6×9 inches, 230 illus. Price, $6.00.

This volume presents a very satisfactory compilation and digest of current knowledge of the geography and geology of the oil fields within the United States.

The subject is discussed by major structural provinces, with sketch maps, graphic columnar sections, stratigraphic tables, and tables of productive formations for each area of importance. The 629 pages of text are extensively and well illustrated, and bibliographies of selected references are given for each province and subprovince.

The book will be of great service to those teaching oil geology, and will also serve a very useful purpose as a general library reference work.

W. T. THOM, JR.

PRINCETON, NEW JERSEY
May 17, 1930

Kentucky Geological Maps. Prepared by the KENTUCKY GEOLOGICAL SURVEY, Willard Rouse Jillson, director (Frankfort, 1920-1930). Price list of maps and publications on request.

The Kentucky Geological Survey has prepared and issued 191 county maps and 8 regional maps bearing on the geological situation in the state of Kentucky. They are attractively printed on a good grade of paper and are commonly considered accurate within the limits set by the director. Other state geological surveys would do well to undertake a similar program of careful mapping, thereby meeting the primary needs of economic geologists.

The *Geologic Map of Kentucky* (scale 1:500,000) was issued in 1929. Geologic formations are shown in colors. Axes of regional and major folds and faults are located. Areal limits of the Pennsylvanian formations (Monongahela, Conemaugh, Allegheny, and Pottsville) are shown. In eastern Kentucky the areal distribution of these formations clearly delineates two major synclines or basins: (1) in Boyd and Lawrence counties, and (2) in parts of Floyd, Breathitt, Knott, Perry, Leslie, and Harlan counties. They are separated by an uplift extending from Rowan and Magoffin counties through Floyd to Pike county. Regional surface and subsurface structure does not substantiate the eastern Kentucky geosyncline shown by the survey in southeast parts of the state. The same formations in western Kentucky delineate the Western Coal Basin, a structural feature terminating in the Cumberland saddle that separates the Cincinnati (Jessamine) dome from the Nashville dome. Oil and gas pools of the state are outlined. County lines and drainage are shown.

Thirty-nine surface structure maps by counties are available. They are contoured on a 10-foot interval (scale, 1 inch = 1 mile), and show drainage, roads, towns, and oil and gas development. Surface formations are outlined on the more recent maps of this group. Each map of the group has a surface and subsurface columnar section of the local rocks. An important contribution to structural geology, these maps are especially valuable at this time in connection with shale-gas exploration in eastern parts of the state.

Areal geologic maps of 65 counties of the state have been prepared. These maps show surface distribution of geologic formations and their members, drainage, towns, roads, and oil and gas development. The maps are on a scale of 1 inch = 1 mile, and include a columnar section of rocks exposed. Stratigraphic subdivisions are shown in standard colors on 45 maps of this group. Structure contours appear on many of the maps.

Subsurface structure maps for 8 counties have been issued. They are on a scale of 1 inch = 1 mile, and are contoured on conspicuous subsurface key beds. The contour interval is generally 10 feet. Columnar sections of rocks penetrated by the drill accompany each map. Drainage and culture are shown, as well as oil and gas development as of the date of issue.

Oil and gas maps of 27 counties, showing oil and gas development, drainage, and culture have been published. Development is that of the date of issue.

HENRY A. LEY

TULSA, OKLAHOMA
June, 1930

Handbuch der Geophysik, Band 4, *Erdbeben* (Earthquakes). By B. GUTENBERG, H. P. BERLAGE, and A. SIEBERG. Gebrüder Borntraeger (Berlin, 1929). 686 pages, 401 illustrations.

The book contains five parts.

I. "Theory of Earthquake Waves," by Gutenberg: propagation of disturbances in a continuous medium, the paths of earthquake waves in the earth's interior, theory of surface waves, preliminary waves in distant earthquakes, observations of near earthquakes, observations of surface waves. Most of the discussion is mathematical and will be understood by few geological-geophysicists.

II. "Seismic Unrest," by Gutenberg: seismic unrest caused by industry and vehicles, by waterfalls, by volcanic processes, by storms and change of air pressure, by wind, by waves; amplitude of the unrest of a period of $^4/_{10}$ seconds and its origin and propagation.

III. "Seismometers," by H. P. Berlage: review of seismometers, constructive details, theory of seismographs, description and manipulation of seismographs.

IV. "Interpretation of Seismograms," by H. P. Berlage: determination of the true ground movement at the station, determination of the focus of distant and of near earthquakes, list of earthquake stations.

V. "The Geology of Earthquakes," by A. Sieberg: the geological and mechanical conditions, dynamics of earthquakes, the areal distribution of earthquake intensities, relation between earthquake intensities and the subsurface, damage to buildings and precautions against damage to buildings, deformation of the earth's surface, effects on terrestrial water, sources of the energy of earthquakes, classification of earthquakes, dynamics of tectonic processes and earthquakes, earthquakes due to the collapse of caverns, eruptive earthquakes, marine quakes, seismic "tidal" waves, earth noises, light phenomena with earthquakes, outline for the investigation of earthquakes.

This is a most scholarly work, packed with information. It is a book for the specialist and not for the beginner or layman. The geologist-geophysicist will find the mathematical treatment of the seismic theory too impractical.

DONALD C. BARTON

HOUSTON, TEXAS
June 28, 1930

RECENT PUBLICATIONS

ASIA

The Structure of Asia, by J. W. Gregory, Franz Ed. Suess, H. de Böckh, D. I. Mushketov, George B. Barbour, Charles P. Berkey, *et al.* Methuen and Company, Ltd., 36 Essex Street, W. C., London (1929). 227 pp. (including indices of authors, localities, and subjects), 8 illus., 18 folding maps, 18 diagrams. Price, 15 s. net.

AUSTRALIA

"Aufbau und Tektonik des Festlandes von Australien," by Walter Geisler. *Geol. Rund.* (Berlin, 1930), Vol. 21, No. 2, pp. 109-23.

CALIFORNIA

"Aerial Photography and Its Importance to California Geologists," by Leon T. Eliel. *Mining in California*, Vol. 26, No. 1 (January, 1930), pp. 64-71, 6 illus. Department of Natural Resources, Division of Mines, Ferry Building, San Francisco, California.

CANADA

The Province of New Brunswick, Canada: Its Natural Resources and Development, by L. O. Thomas. Natural Resources Intelligence Service, Ottawa, Canada (1930). 167 pp., illus. "Minerals," including geology and petroleum, pp. 85-115.

"The Oilfields of Alberta," by E. H. Cunningham Craig. *Jour. Inst. Petrol. Tech.*, Vol. 16, No. 82 (May, 1930), pp. 390-422, 4 figs.

GENERAL

Geological Nomenclator, edited by L. Rutten. Contents: "Exogenic Processes and Physiography," by W. E. Boerman and K. Oestreich; "Tectonic Geology," by G. A. F. Molengraaff; "Volcanology," by B. G. Escher; "Seismology," by G. Van Dijk; "Slow Changes in Levels and Mountain Building," by L. Rutten; "Stratigraphy and General Palaeontology," by P. Kruizinga; "Petrology," by J. A. Grutterink; "Ore Deposits," by H. F. Grondijs and C. Schouten; and "Alphabetical Index," by L. Rutten. Publication of *Geologisch Mijnbouwkundig Genootschap voor Nederland en Koloniën* (1929). G. Naeff, Vos in 't Tuintje 1, The Hague, Holland. In Dutch, German, English, and French. 339 pp., 58 illus., 4to cloth. Price, Guilder 21 ($8.50).

IIe Congrès International de Forage (Second International Drilling Congress, Paris, September 16-23, 1929). Fifty-six technical papers or more, printed in French, Italian, English. Société Anonyme de l'Imprimerie Théolièr, 12 Rue Gérentet, Saint Etienne.

Oil and Petroleum Year Book (1930), edited and published by Walter E. Skinner, 15 Dowgate Hill, Cannon Street, London, E. C. 4. Twenty-first edition of this well known international reference of oil companies. 430 pp. Cloth. Price, 7 s. 6 d. net; or post free, 8 s. 6 d.

"Sedimentation Committee Report for 1928-29," by 19 authors. *National Research Council Reprint and Circular Series No. 92* (1930). (1) "Introduction," W. H. Twenhofel; (2) "The Intertidal Zone of the Wash, England," E. M. Kindle; (3) "Research on Sediments by British Geologists for the Year 1928," Henry B. Milner; (4) "Bibliography of Research on Sediments by European Geologists in 1927 and in Part in 1928," Édouard Paréjas; (5) Silt Studies on American Rivers," Kirk Bryan; (6) "Studies on Marine Bottom Deposits at the Scripps Institution of Oceanography," T. Wayland Vaughan; (7) "Research on Marine Bacteriology," A. H. Gee; (8) "Calcium Carbonate in Sea Water," A. H. Gee and E. G. Moberg; (9) "Research on Marine Sediments Conducted by the American Petroleum Institute," Parker D. Trask; (10) "Studies in

Sedimentation at the Jacques Loeb Laboratory, Stanford University," L. B. Becking; (11) "Recent Publications on Chert, Flint, Concretions, Cone-in-Cone, and Stylolites," W. A. Tarr; (12) "Varved Sediments," Ernst Antevs; (13) "Sedimentational Research on the Pacific Coast," R. D. Reed; (14) "Micropaleontology in the Mid-Continent Region," Dollie Radler; (15) "Heavy Mineral Work in the Mid-Continent Region," Fanny Carter Edson; (16) "Lake Deposits in the Basin and Range Province," Eliot Blackwelder; (17) "Bibliography on Chemical Studies Which Bear on Sedimentation," George Steiger; (18) "Studies of Glacial Sediments in 1928," M. M. Leighton; (19) "Investigations of Fluvial Deposits," A. C. Trowbridge. (National Research Council Division of Geology and Geography, B and 21st Streets, Washington, D. C.) 122 pp., bibliographic lists. Price, $1.00.

"Überblick über die Geologie der tschecho-slowakischen Karpathen," by Karl Zapletal. *Geol. Rund.* (Berlin, 1930), Vol. 21, No. 2, pp. 124-40, 1 fig., bibliography.

"Leading Oil Fields Abroad." Map. *Oil Field Eng.* (Philadelphia, June 1, 1930), p. 48.

Increasing the Recovery of Petroleum, by Wentworth H. Osgood. (McGraw-Hill Book Company, Inc., 370 Seventh Avenue, New York, N. Y., 1930). Two volumes, 858 pp., 163 illus. Price, $10.00.

GEOPHYSICS

"Choice of Geophysical Methods," by Frank Rieber. *Min. and Met.* (New York, June, 1930), pp. 301-5, 9 figs. Discussion by N. H. Stearn.

Geophysical News and Review of Geophysical Literature, Vol. 2, No. 2 (May, 15, 1930). By J. A. Malkovsky, C. A. Heiland, and Dart Wantland. Dept. Geophysics, Colorado School of Mines, Golden, Colorado.

KANSAS

"Voshell Area in McPherson County," by T. C. Hiestand. *Oil and Gas Jour.* (Tulsa, Okla., June 5, 1930), pp. 36, 331-33, 3 figs.

MOROCCO

"Communication sur le pétrole au Maroc," by J. Jung. *IIe Congrès International de Forage* (Second International Drilling Congress, Paris, September 16-23, 1929). 6 pp., 3 illus.

OKLAHOMA

"Engineering Study of the Seminole Area, Seminole and Pottawatomie Counties, Oklahoma," by R. R. Brandenthaler, W. S. Morris, and C. R. Bopp. *U. S. Bur. Mines Rept. of Investigations 2997*, in coöperation with the State of Oklahoma. (Petroleum Experiment Station, United States Bureau of Mines, Bartlesville, Oklahoma, May, 1930.) Free.

RUSSIA

Geological maps of the U. S. S. R., published in 1925 and 1926, in about 20 colors, in 7 sheets, can be purchased from the Amtorg Trading Corporation, 19 West 27th Street, New York City, for $6.65 postpaid. Russia is covered

in one sheet, size 24×20½ inches; scale, 1:6,300,000. Siberia is covered in the other sheets, six being of the same size as the one Russian sheet with one small additional sheet 12×4 inches; scale, 1:4,200,000.

TURKEY

"Das Oelgebiet von Turka am Stryj, Kleinpolen," by Emil Bartel. *Intern. Zeits. für Bohrtechnik, Erdölbergbau und Geologie* (Vienna, June 1, 1930), pp. 103-7.

WASHINGTON

"Description of Washington Geology," by Louis Z. Johnson. *Calif. Oil World* (Los Angeles, May 29, 1930), pp. 7, 18.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these applicants, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

FOR ACTIVE MEMBERSHIP

Joseph L. Adler, Denver, Colo.
E. D. Phillips, L. F. Athy, S. H. Williston
Peter Karl Staehelin, Puerto Mexico, Ver., Mexico
H. I. Tschopp, Alfred P. Frey, H. S. Thalmann

FOR ASSOCIATE MEMBERSHIP

Hugh Andrews, San Angelo, Tex.
Don Danvers, F. K. Foster, H. Smith Clark
Harry X Bay, Iowa City, Ia.
A. C. Trowbridge, A. C. Tester, F. B. Plummer
Benjamin C. Craft, Baton Rouge, La.
H. V. Howe, G. D. Hanna, R. B. Grigsby
Fay Coil, Norman, Okla.
C. E. Decker, V. E. Monnett, A. J. Williams
Raymond E. Crist, Maracaibo, Venezuela, S. A.
C. M. Nevin, H. Ries, W. Storrs Cole
Alden S. Donnelly, Midland, Tex.
E. Russell Lloyd, Prentice F. Brown, Romaldo DeChicchis
Ross Haskins Field, Pincher Creek, Alta., Canada
Linn M. Farish, S. E. Slipper, Theodore A. Link
Harley S. Gibbs, Pittsburgh, Pa.
Roswell H. Johnson, Ionel I. Gardescu, R. E. Somers
Paul K. Goodrich, San Angelo, Tex.
Phillip Maverick, W. H. Conkling, R. E. Rettger
Wallace W. Irwin, Midland, Tex.
Robin Willis, Lon D. Cartwright, Jr., H. E. Munson
Jess Ray Jones, Meridian, Miss.
B. W. Blanpied, S. E. Mix, Roy T. Hazzard
Arne Junger, Los Angeles, Calif.
E. F. Davis, Roy R. Morse, Leslie M. Clark
John Berridge Kay, Maracaibo, Venezuela, S. A.
J. A. Hoekstra, H. E. van Aubel, J. B. Burnett

Albert Douglas Miller, Dallas, Tex.
Alfred Gray, Edgar Kraus, Niles B. Winter
Dewitte T. Neill, Clinton, Okla.
J. M. Lilligren, C. A. Yoakam, Grant W. Spangler
Hampton Smith, Los Angeles, Calif.
E. K. Soper, James T. Wood, Jr., R. D. Reed
Maurice R. Teis, Tulsa, Okla.
C. E. Decker, V. E. Monnett, A. J. Williams
Howard J. Van der Veer, Washington, D. C.
W. A. Waldschmidt, J. Harlan Johnson, F. M. Van Tuyl

FOR TRANSFER TO ACTIVE MEMBERSHIP

Robert L. Cassingham, Enid, Okla.
Dollie Radler, John L. Ferguson, R. L. Clifton
Margaret Cameron Cobb, New York, N. Y.
Dollie Radler, E. L. DeGolyer, C. V. Millikan
Harold S. Forgeron, Midland, Tex.
E. Russell Lloyd, Prentice F. Brown, A. L. Ackers
Wilson Gordon Saville, Houston, Tex.
Sidney Powers, Andrew Gilmour, Donald C. Barton

EXECUTIVE COMMITTEE MEETING, TULSA, MAY 23, 1930

The executive committee met at Tulsa, Oklahoma, May 23, 1930. Three members were present: president Sidney Powers, of Tulsa, Oklahoma; second vice-president Marvin Lee, of Wichita, Kansas; and third vice-president F. H. Lahee, of Dallas, Texas.

Constitutional Amendments.—The report of the ballot committee, composed of Arthur W. Duston, *chairman*, Gerald A. Waring, and Harry F. Wright, was approved and the constitution was declared amended in accordance with the letter-ballot of April 21, 1930. The vote was 861 for, and 65 against. Seven ballots were returned blank. The entire new constitution, as amended by this ballot, and the entire new by-laws, as amended by vote of the fifteenth annual business meeting at New Orleans, are printed on pages 671-77 of the May *Bulletin*.

Revolving Publication Fund trustees.—It was recommended that three trustees of this fund be authorized by the Association at the next annual meeting, each to serve, in rotation, for three years, and that the appointment of trustees be made by the executive committee whenever vacancies occur.

Research Fund trustees.—It was likewise recommended that three trustees of this fund be authorized by the Association at the next annual meeting, each to serve, in rotation, for three years, that the chairman of the research committee be ex-officio one of the members, and that the other two be appointed by the executive committee.

Investments.—A resolution was passed that investments of $1,000.00 or more be made only in readily negotiable bonds and that the approval of a majority of the executive committee must be secured before such investments are made.

I. C. White medal.—The executive committee last year approved the authorization of an I. C. White medal[1] to be awarded to petroleum geologists for distinguished contributions to their science. It was decided that the method for awarding this medal be referred for suggestions and approval to the Association business committee at its next annual meeting.

EXECUTIVE COMMITTEE MEETING, FORT WORTH, JUNE 4, 1930

The executive committee met at Fort Worth, Texas, June 4, 1930. Four members were present: president Sidney Powers, past-president J. Y. Snyder, second vice-president Marvin Lee, and third vice-president F. H. Lahee.

In addition to other matters of business considered, the committee appointed the president of the Association to be chairman and the second vice-president to be secretary of the executive committee for the current year.

[1]See page 1233 of the *Bulletin* for September, 1929, and pages 875-79 for July, 1929.

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

SIDNEY POWERS, *chairman*, Box 2022, Tulsa, Oklahoma
MARVIN LEE, *secretary*, 612-18 Brown Building, Wichita, Kansas
J. Y. SNYDER, 1211 City Bank Building, Shreveport, Louisiana
R. D. REED, 1110 Glendon Way, South Pasadena, California
F. H. LAHEE, Box 953, Dallas, Texas

GENERAL BUSINESS COMMITTEE

E. DEGOLYER (1931), *chairman*, 65 Broadway, New York, N. Y.
ALEXANDER DEUSSEN (1931), *vice-chairman*, 1606 Post Dispatch Building, Houston, Texas

SIDNEY POWERS (1931)
J. Y. SNYDER (1931)
R. D. REED (1931)
MARVIN LEE (1931)
FREDERIC H. LAHEE (1931)
M. G. CHENEY (1931)
VICTOR COTNER (1932)
R. E. SOMERS (1931)
HUBERT E. BALE (1931)
THEODORE A. LINK (1931)
H. B. FUQUA (1931)
A. C. TROWBRIDGE (1931)
J. M. VETTER (1931)
S. A. GROGAN (1931)
H. J. WASSON (1931)
E. F. DAVIS (1931)
FRANK A. MORGAN, JR. (1931)
CHARLES M. RATH (1931)
R. F. IMBT (1931)
CHAS. H. ROW (1931)
S. P. BORDEN (1931)
R. E. DICKERSON (1931)
A. W. DUSTON (1931)
A. I. LEVORSEN (1931)
L. W. KESLER (1931)
DONALD C. BARTON (1931)
ALEX W. MCCOY (1931)

RESEARCH COMMITTEE

ALEX W. MCCOY (1932), *chairman*, 919 East Grand Avenue, Ponca City, Okla.
DONALD C. BARTON (1933), *vice-chairman*, Petroleum Building, Houston, Texas

K. C. HEALD (1931)
F. H. LAHEE (1931)
R. C. MOORE (1931)
F. B. PLUMMER (1931)
M. K. READ (1931)
C. R. FETTKE (1932)
A. I. LEVORSEN (1932)
SIDNEY POWERS (1932)
R. D. REED (1932)
L. C. SNIDER (1932)
W. C. SPOONER (1932)
W. T. THOM, JR. (1932)
F. M. VAN TUYL (1932)
W. E. WRATHER (1932)

REPRESENTATIVES ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

ALEX W. MCCOY (1931)
R. C. MOORE (1933)

REPRESENTATIVES ON NATIONAL STRATIGRAPHIC NOMENCLATURE COMMITTEE

A. I. LEVORSEN, *chairman*, Independent Oil and Gas Company, Philtower Building, Tulsa, Okla.

M. G. CHENEY
C. J. HARES

NOMINATING COMMITTEE FOR POPULAR SCIENCE MONTHLY COMMITTEE OF AWARD

L. C. SNIDER, *chairman*, Henry L. Doherty and Company, 60 Wall Street, New York, N. Y.

T. S. HARRISON
C. R. MCCOLLOM

METHOD OF ELECTION OF OFFICERS

W. E. WRATHER, *chairman*, 4300 Overhill Drive, Dallas, Texas
H. B. FUQUA, *vice-chairman*, Box 737, Fort Worth, Texas

A. F. CRIDER
R. E. DICKERSON
W. B. HEROY
J. V. HOWELL
FRANK S. HUDSON

REVOLVING PUBLICATION FUND

E. DEGOLYER, *chairman*, 65 Broadway, New York, N. Y.

RESEARCH FUND

LUTHER H. WHITE, *chairman*, J. A. Hull Oil Company, Tulsa, Oklahoma

AT HOME AND ABROAD

Louis C. Chappuis, geologist and petroleum engineer of Los Angeles, California, will be in Peru from June to September, doing aerial photographing and reconnaissance for the Peruvian government. On the return trip, Mr. Chappuis expects to fly from Peru to Panama, making aerial photographs of the oil-bearing regions along the western coast.

J. M. Alden, formerly deputy supervisor in California, has been appointed supervisor of the Muskogee district of the U. S. Geological Survey.

James H. Gardner, president of the Gardner Petroleum Company, Tulsa, has an article entitled "Domestic Producer Fears Foreign Oil" in the June issue of *Oil Field Engineering*.

Kenneth B. Nowels, supervising engineer of the U. S. Bureau of Mines petroleum research office at Laramie, Wyoming, resigned July 1, to become chief petroleum engineer for the Forest Oil Company at Bradford, Pennsylvania.

Glenn R. V. Griffith is production engineer for the Associated Producers Company, Bradford, Pennsylvania.

Basil B. Zavoico, consulting geologist, Tulsa, Oklahoma, has an article, "What Will Russia Do?" in the June issue of *Oil Field Engineering*.

L. I. Yeager is resident geologist at Wichita, Kansas, for the Empire Gas and Fuel Company.

B. S. Ridgeway is employed by the Empire Oil and Refining Company, in the geological department. His address is Box 816, Chickasha, Oklahoma.

R. C. Beckstrom, consulting engineer for the U. S. S. R., has an article entitled "Russia Is Forging Ahead," in the June number of *Oil Field Engineering*.

E. H. Sellards, associate director of the Bureau of Economic Geology at Austin, Texas, delivered a talk entitled "Pre-Cretaceous Rocks Along the Balcones Fault Zone" before the West Texas Geological Society at San Angelo, Texas, May 24.

Harry W. Oborne, consulting geologist of Colorado Springs and Lamar, Colorado, was in Idaho in June.

W. Earle Shamblin is geologist for the Prairie Oil and Gas Company at Edmond, Oklahoma.

Walter Kauenhowen, of the Mid-Kansas Oil and Gas Company, is working in East Texas.

SIDNEY A. PACKARD has resigned his position as chief geologist for the Louisiana Oil Refining Corporation of Shreveport, Louisiana. His temporary address is 509 West Twentieth Street, Oklahoma City, Oklahoma.

A. E. OLDHAM has resigned from the Amerada Petroleum Corporation to become chief geologist of the Louisiana Oil Refining Corporation of Shreveport, Louisiana. He will continue to work in east and south Texas.

BEN H. PARKER, of Oklahoma City, has resigned from E. W. Marland, Inc.

H. P. BYBEE, of San Angelo, Texas, has announced temperature measurements in the well drilled by P. H. Williams, on the Ash Brothers' ranch, Irion County, as follows: 198° at 8,185 feet, 204° at 8,825 feet. The well encountered salt water in the Ordovician at 8,885 feet.

FRED M. HAASE has resigned from the Shell Petroleum Corporation at Shreveport, Louisiana.

C. C. CLARK, formerly district geologist for the Shell Petroleum Corporation at Shreveport, Louisiana, is geologist for the Louisiana Gas and Fuel Corporation at Shreveport.

MARVIN LEE, chairman of the arrangements committee of the Kansas Geological Society, has issued a preliminary announcement of the annual field conference of the society to be held September 1-6, 1930, commencing at Colorado Springs, Colorado, and ending at Amarillo, Texas. The chief object is to learn more of the subsurface stratigraphy in southeast Colorado, southwest Kansas, northeast New Mexico, and the Oklahoma and Texas Panhandles. For further information and reservations write Mr. Lee, 612 Brown Building, Wichita, Kansas.

ALBERT EMMETT OLDHAM and MARY ESTHER NICHOLS were married on June 4, 1930, at Tyler, Texas.

DAVID B. REGER, of Morgantown, West Virginia, has resigned his position as associate geologist of the West Virginia Geological Survey, effective August 31, 1930. His future plans have not been announced.

M. N. BRAMLETTE, of New Haven, Connecticut, will go to central Asia soon for 2½ years, as geologist for the archaeological expedition of Harvard University and the British Museum. Sir AUREL STEIN will head the expedition.

CHARLES A. DAUBERT is chief geologist for Perkins Cullum at Wichita Falls, Texas.

PHILLIP F. MARTYN is district geologist for the Houston Oil Company. His present address is Box 991, Beeville, Texas.

LOUIS C. CHAPPUIS, petroleum geologist for Olson's Scouting Service, Los Angeles, California, has an article entitled "Oil Discovery in the Vaqueros Great Boost for Belridge" in the June issue of *Petroleum World and Oil Age*.

GEORGE OTIS SMITH, director of the U. S. Geological Survey, Washington, D. C., has a brief article on "Another Year of Coöperative Effort" in the June number of *Oil Bulletin*.

ISAAC N. KNAPP, father of ARTHUR KNAPP, who is petroleum engineer for the United Gas Improvement Company, Philadelphia, Pennsylvania, died in Washington, D. C., May 25, 1930, at the age of 79.

SHEPARD W. LOWMAN, geologist for the Mid-Continent Petroleum Corporation, Tulsa, Oklahoma, has an article entitled "Siliceous Lime Produces at Big Lake" in the June 5 issue of *Oil and Gas Journal*.

RICHARD A. JONES, geologist, San Antonio, Texas, has an article on "Review of Drilling Below 5,000 Feet in West Texas" in the June 6 issue of *Oil Weekly*.

CHARLES E. DECKER and E. O. ULRICH were leaders of the eighteenth field conference sponsored by the Oklahoma Geological Survey, studying the Simpson formation of the Arbuckle Mountains, June 13 and 14, 1930. More than 100 geologists were in attendance, including men from Oklahoma, Kansas, Texas, Missouri, California, and Washington, D. C. Night stops were made at Ardmore and Ada, and discussions were led by ULRICH, DECKER, J. T. RICHARDS, FRANK GOUIN, FRED BUSH, ROBERT M. WHITESIDE, JOHN FITTS, and others.

JAMES L. TATUM, chief geologist of the Continental Oil Company of Mexico, S. A., has moved his office and residence to Monterrey, Mexico, from Laredo, Texas. The extensive holdings of the Continental Oil Company, formerly Marland, in northern Mexico, were taken as a result of Mr. Tatum's work.

C. P. COLLINS has returned to the United States from Brighton, Trinidad, B. W. I., where he has been employed by The Trinidad Lake Petroleum Company, Ltd. His address is 10 Lincoln Street, Woodstock, Vermont.

JAMES D. SISLER, associate state geologist of Pennsylvania, has been elected state geologist of West Virginia. He assumed his duties at Morgantown on July 1.

J. S. ROSS resigned June 15 from his position as petroleum engineer for the United States Bureau of Mines at Shreveport, Louisiana, to accept a position as engineer for the Southern States Company of Shreveport.

L. O. WHYMAN, for many years scout for the Empire Gas and Fuel Company, and for the past few years located in San Antonio, Texas, died recently at his home in San Antonio.

The Shreveport Geological Society held its Eighth Annual Field Trip, June 14-15. The trip was made through southwestern Arkansas by auto bus to study the Cretaceous and Comanche formations. The party left Texarkana, Arkansas, Saturday morning and spent the night at DeQueen. Approximately thirty-three geologists made the trip. M. W. GRIMM is president and W. F.

CHISHOLM is secretary-treasurer of the Society. GEORGE C. BRANNER, Arkansas state geologist, accompanied the party.

LLOYD NORTH is consulting geologist at Houston.

B. C. RENICK has accepted a position as geologist for the Vacuum Oil Company at San Antonio.

R. E. SHUTT, of the Shell Petroleum Corporation, has been transferred temporarily from St. Louis to Tulsa during the absence of T. K. HARNSBERGER, who is in Europe for his health.

THOMAS S. HARRISON, consulting geologist of Denver, Colorado, is spending the summer in California, and can be reached at 734 Pacific Mutual Building, Los Angeles.

ELIOT BLACKWELDER, professor of geology at Stanford, has returned to the university after a field trip to the Mohave Desert.

RAYMOND C. MOORE, state geologist of Kansas, at Lawrence, is working on the compilation of a new geological map of Kansas on the scale of 1:500,000.

PHILIP B. KING, of the U. S. Geological Survey, is spending the summer mapping the Marathon uplift of Texas in detail.

LON D. CARTWRIGHT, JR., is geologist at San Angelo for the Superior Oil Company.

CARY P. BUTCHER is geologist at San Angelo for Cranfill and Reynolds.

WILLIAM H. FOSTER, consulting geologist of Tulsa, is spending the summer in the field in Texas.

FRED DAVIES, of The California Company, is working in Asia Minor.

WILLIS A. MALEY is geologist for the Humble Oil and Refining Company at Corpus Christi, Texas.

GEORGE D. STEVENS, of Cranfill and Reynolds, is now stationed at Houston.

DAVID DONOGHUE, of Fort Worth, has been appointed technical adviser to the joint committee of the Independent Petroleum Association and the Mid-Continent Oil and Gas Association of Texas and the pipe line companies of Texas, working toward the enforcement of the new Common Purchaser law of the State of Texas, which took effect June 20.

JOHN M. MUIR is now geologist for the Southern Crude Oil Purchasing Company at Fort Worth, Texas.

KARL E. YOUNG has organized the Louisiana Paleontological Laboratories, Inc., at Lafayette, Louisiana.

G. MOSES KNEBEL, who has represented the Humble Oil and Refining Company in East Texas for many years, has been transferred to Venezuela, where he will be geologist for the Creole Petroleum Corporation.

DWIGHT H. BINGHAM has resigned from the Gulf Production Company, Houston, Texas, to accept a position with the Creole Petroleum Corporation, in Venezuela.

WALTER M. BURRESS is geologist for the Louisiana Oil Refining Corporation, of Shreveport.

L. G. WELCH, of the executive department of the Louisiana Oil Refining Corporation, is living at Fort Worth.

JOHN Y. SNYDER announces the discovery of a black, aphanitic igneous rock in the wildcat well recently drilled by the Evansville Investment Company on the Welch SW. corner, Sec. 2, T. 14 N., R. 8 E., Franklin Parish, Louisiana, at a depth of 4,266-4,289 feet, the total depth.

WILLIAM J. NOLTE, recently of the consulting business, is now district geologist for the Dixie Oil Company, Inc., at Wichita Falls, Texas.

VIRGIL R. D. KIRKHAM, Lansing, Michigan, has an article on "The Moyie-Lenia Overthrust Fault," in the *Journal of Geology* for May-June.

JOHN G. BARTRAM, of the Midwest Refining Company, Denver, Colorado, has an article on "Triassic-Jurassic Red Beds of the Rocky Mountain Region: A Discussion" in the May-June issue of the *Journal of Geology*.

OSCAR HATCHER, Seminole, Oklahoma, has resigned as district geologist for the Gypsy Oil Company, to become consulting geologist for J. C. Shaffer, Inc., 1218 Perrine Building, Oklahoma City.

GEORGE SHEPPARD, state geologist for the Republic of Ecuador, Guayaquil, has an article on "The Igneous Rocks of Southwest Ecuador" in the May-June issue of the *Journal of Geology*.

C. P. PARSONS, of the Halliburton Oil Well Cementing Company, Duncan, Oklahoma, has an article on "Admixtures in Rotary Mud" in the June 20 issue of the *Oil Weekly*. This paper, which is also published in the June 12 issue of the *Oil and Gas Journal*, was presented before the May 23, 24, 1930, meeting of the Mid-Continent District of the American Petroleum Institute, Division of Production.

LESTER C. UREN, professor of petroleum engineering at the University of California, Berkeley, California, has an article entitled "60-Foot Caissons Used for Rig Supports in Drilling Off-Shore Leases," in the June 18 issue of *National Petroleum News*.